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PAPERS FROM THE DEPARTMENT OF MARINE BIOLOGY

OF THE CARNEGIE INSTITUTION OF WASHINGTON

VOLUME XXIII.

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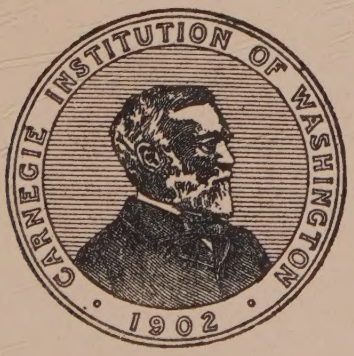

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SOME MARINE BOTTOM SAMPLES FROM PAGO PAGO HARBOR, SAMOA.

By M. N. Bramlette.

With one map and eight text-figures.

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SOME MARINE BOTTOM SAMPLES FROM PAGO PAGO HARBOR, SAMOA.

By M. N. Bramlette.

INTRODUCTION.

A knowledge of the sediments and processes of sedimentation of the present is essential to the interpretation of the sedimentary rocks formed in the geological past. The object of this study has been to gain some quantitative as well as the more usual qualitative data on the sediments being deposited in a tropical island embayment, having a fringing "coral" reef. The study was projected and supervised by Dr. T. Wayland Vaughan, the materials and data having been furnished by the late Dr. A. G. Mayor, Director of the Department of Marine Biology of the Carnegie Institution of Washington. Doctor Mayor, in his studies of American Samoa, made the collection of marine bottom samples from the reefs and bottom of Pago Pago Harbor, Tutuila, and also obtained very complete data on environmental conditions, so that this data will be presented in considerable detail in tables and graphs in the Appendix.

In studying these samples, three main means of investigation were employed, the mechanical analysis, the chemical analysis, and petrographic study of the materials. The mechanical analyses were made by the Bureau of Soils, U. S. Department of Agriculture, and are not entirely adapted to such a study as the one here undertaken, but were so analyzed as a matter of expediency; the results seem fairly satisfactory in the absence of any accepted standards for such investigations. The method of analysis consists in screening the sands for separation into five grades of gravel and sand; the materials below sand grade are separated into the silt and clay grades by means of the centrifuge.

The chemical analyses were made by Mr. J. G. Fairchild, of the chemical laboratory of the U. S. Geological Survey, the samples all being subjected to a rather complete analysis, as shown in the tables, though the most significant part of this work is, of course, the ratios of magnesium carbonate, calcium carbonate, and insoluble material.

The petrographic study consisted in the determination of the constituent grains of each grade of each sample. In two samples taken as types this determination was carried out to obtain actual quantitative data on the composition. A sample of about 100 grains of each grade was studied to determine the nature of each individual

grain and its percentage of the total. The grains were studied first under the binocular microscope and such as were indeterminate thus were studied under the polarizing microscope, the minerals being determined by their optical properties, the organic grains by their microstructure. The rest of the samples were studied by making a similar count on only one or two grades usually, and a more casual inspection of the other grades for an approximate composition or comparative estimate of difference from the carefully studied grade.

Types of sediments.—The sediments forming in this embayment in tropical waters are a resultant of three contributing factors, the growth and destruction of the fringing reefs, the accumulation of the tests of non-reef-forming organisms living in the waters and on the bottom, and the detritus brought down by the streams and deposited. Corresponding to these three contributing agencies, there are three types of sediments forming with all gradations and intermixtures of the reef-sand, the calcareous mud, largely of the tests of non-sessile organisms, and the inorganic sands of rock material.

The most striking fact about the reef rock is, as noted at Funafuti[1] and elsewhere, that corals are not the most important organisms, quantitatively at least, and are not even the dominant single constituent, being exceeded by calcareous algæ. As a skeletal structure or reinforcing framework, the corals are very important, but in this sense only might the reef be considered a coral reef and might more properly be designated an algal reef.

The reef sands or calcarenytes on the reef and deposited near it in the adjacent off-reef bottom are correspondingly not coral sands, and show coral even a less important constituent, as the latter is not so easily disintegrated by the destructive agencies at work. More important are the calcareous algæ, again, and also of importance are mollusks, foraminifera, crustacea, and various other organisms.

The calcareous silts or calcilutytes contain a considerable admixture of the finer material of reef destruction, but more important are the mollusks, foraminifera, pteropods, ostracods, and other organisms of pelagic and benthonic character. They are much better sorted and have a considerable percentage of colloidal material present.

Near the mouths of the streams entering the bay the sediment is dominantly an inorganic sand, consisting of basaltic, pumiceous, and glassy rock fragments, and mineral fragments, especially magnetite. Though the country rocks are highly weathered, and the fragments of them much altered, the mineral grains are perfectly fresh. The feldspars are clear and unaltered, as are the more easily weathered ferromagnesian minerals, and even the olivine crystals are perfectly fresh. All these mineral grains probably represent phenocrysts in the

[1] J. J. Hinde. Report on the materials from the borings at the Funafuti Atoll. Atoll of Funafuti, p. 186, 1904.

volcanic country rock, and indicate the comparative ease with which the fine ground-mass disintegrates in weathering, before the phenocrysts are affected. There is, of course, a slight admixture of organic material in all of this inorganic sand deposited in the waters of the bay, and only very locally is it the dominant type.

Between the three types of sediment there are all gradations, but generally one of the three is distinctly dominant.

The two samples later collected from Nuuli Lagoon are rather similar to the reef samples, except for a higher inorganic content, and they show an unusually large percentage of calcareous prisms from mollusk-shell disintegration and siliceous-sponge spicules, both axial and ovoid. It seemed that the physico-chemical conditions might be more favorable for a chemical precipitation of $CaCO_3$ in this lagoon, but no evidence of such a precipitate was found in these samples.

ENVIRONMENTAL CONDITIONS.

Tutuila, American Samoa, is a tropical Pacific island, at 14° S. latitude and 170° W. longitude. It is a volcanic island composed, according to Professor Daly,[1] of flows, agglomerates, and tuffs of basalt. Associated with these basic volcanics are necks and dike-like masses of alkaline trachytes. He says:

> "Erosion has been clearly controlled by the relative strengths of these rocks. The special resistance of the trachyte and phonolite to the weather explains the bold projection of the peaks and ridges of Matafao, Pioa, Papatels, Afona Bay, and of Cockscomb Island and the heights to the southwestward—The valleys have been sunk in the weaker lava flows and the still weaker pyroclastics."

He considers the harbor of Pago Pago to be, in part at least, a resultant of the foundering of a volcanic crater. The volcanic pyroclastics which are the dominant type about the harbor are very highly weathered.

Around the harbor the land rises, often precipitously and elsewhere at steep angles, to heights of 1,000 feet or more, and the slopes are densely forested with tropical vegetation. The short mountain streams flowing into the harbor carry a load of volcanic-rock débris, which it quickly deposits on reaching the small alluvial flat or on flowing into the bay, as the inorganic material is localized near the stream mouths, except for some of the finest silt and clay sizes.

A recent fringing "coral" reef occupies the shores of the harbor, and the dominance of calcareous algæ makes the reef more properly an algal reef than a coral reef. The incrusting lithothamnion covers the outer face of the reef, while the fragile *Halimeda* is abundant on

[1] R. A. Daly. Geology of American Samoa. Carnegie Inst. Wash. Year Book No. 18 for year 1919, p. 192.

the reef flat. Doctor Mayor has studied these reefs very intensively and presents the results in several interesting papers.[1]

The climate of the island is warm and humid, the mean annual temperature being 81.0° F. for the years 1902 to 1919, inclusive, the highest record being 97° on May 6, 1920, and the lowest 70° on August 11, 1903, and October 16, 1919. The mean annual rainfall for the years 1900 to 1920, inclusive, is 196.1 inches. On an average 28 torrential showers of 2 inches or more occur each year; thus, 95 inches of rain falls annually in these torrents, or about one-half of the total annual rainfall. The highest recorded fall was 20 inches in a few hours on May 17, 1912. In the four days from June 28 to July 1, 1920, there was a fall of 37.5 inches, which killed thousands of corals, some of them 50 years old.

The chemical analysis of the sea-water off the harbor of Pago Pago made by Professor A. H. Phillips and given subsequently, shows it to be a normal sea-water of about the average salinity. Within the harbor off Pago Pago Brook, about 250 feet from shore, the salinity ranged in April 1917, from 0.92 to 31.38 per thousand and the temperature from 30.9° to 24.8°C., based on 9 days of observation. The salinity of 0.92 was caused by a shower of 4.3 inches which occurred in about 4 hours and produced an abnormal freshet in Pago Pago Brook. In another set of ten observations off outer end of Blacklock's wharf, the salinity ranged from 15.52 to 34.04 per thousand and the temperature from 25.4° to 29.4°C. In the ocean water close outside the harbor the salinity ranged from 34.82 to 34.86 per thousand and the temperature from 28.0° to 29.0°C. Thus the difference in temperature between the inner part of the harbor and the mouth is practically negligible, due, doubtless, to the great depth of water in the harbor, but the salinity ranges considerably, especially the surface salinity, after heavy showers.

ORGANISMS CONTRIBUTING TO THE REEF AND REEF SANDS AND THEIR RECOGNITION.

The most important contributor, quantitatively, is the group of calcareous algæ including *Halimeda*, *Lithothamnium*, and corallines. Recognition of these forms in the sand is usually not difficult, either by their shape and external markings, the white opacity and fine granularity, or by their structure under the microscope.

[1] A. G. Mayor. The reefs of Tutuila, Samoa, in their relation to coral-reef theories. Proc. Amer. Phil. Soc., vol. 43, No. 3, 1920.

———. Coral reefs of Tutuila, with reference to the Murray-Agassiz solution theory. Proc. Nat. Acad. Sciences, vol. 3, Aug. 1917, pp. 522-526.

———. The growth-rate of Samoan coral reefs. Proc. Nat. Acad. Sciences, vol. 4, Dec. 1918, pp. 390-393.

———. Causes which produce stable conditions in the depth of the floors of Pacific fringing reefs.

The madreporarian corals probably rank second in importance as contributors of material, though their importance would be underestimated if examined casually, as at Funafuti, because they are not easily recognized by form. The form usually helps little in their recognition except in large fragments, but there is a certain translucency to the fragments that is characteristic, and under the microscope the trabecular structure and radial prismatic structure are good diagnostic criteria.

Mollusks contribute a large percentage of calcareous material and their fragments are easily identified from the external form, markings, and colors; or under the microscope by the strong prismatic character and the clear, strong birefringence. Pelecypods, gastropods, and scaphopods are all abundant.

Crustaceans are common; though contributing only a few per cent of the total, they are recognized by a fine prismatic structure or fibrousness, but clouded in appearance and without the clear bright birefringence of mollusk. The form and markings of the fragment are usually diagnostic, if of sufficient size. Most common are fragments of decapods, but ostracods are rather abundant.

Foraminifera contribute several per cent of the total and are very easily recognized, even as comminuted fragments. The foraminifera have been studied by Doctor Cushman[1] and are described in a published work. *Baculogypsina* and *Amphistegina* are two of the largest and most abundant forms, with *Orbitolites* very much less important.

Echinoid spines and fragments of plates are not uncommon and are among the easiest constituents to recognize, either megascopically or microscopically.

Bryozoa are ubiquitous but in very minor percentage and are usually of the branching rather than incrusting forms. They can usually be recognized by their external form, but have very little that is characteristic or diagnostic in their microscopic structure, and may occasionally be unrecognized or mistaken for mollusks or other organism fragments.

Alcyonarian spicules are also usually common, though not in important quantities, and are easily recognized from their external form.

Millepores, though present, were not easily recognized and were probably mistaken for madrepores occasionally, but are not of quantitative importance as contributing organisms.

Spirorbis, *Serpula*, and other worms are present in small quantities and are more easily recognized by external form than by microscopic structure.

Sponge spicules, both siliceous and calcareous, are common in small quantities, the siliceous spicules being usually monaxons, but also

[1] J. A. Cushman. Samoan Foraminifera. Carnegie Inst. Wash. Pub. No. 342; see also the fina paper in this volume.

including an ovoid form; the calcareous spicules are commonly triaxons, but include tetraxons and polyaxons. These spicules are all easily recognized by their external form.

Ascidian spicules of various stellate shapes are common in the finest grades of the materials and can be recognized by their external form.

Diatoms are very uncommon, contributing no appreciable quantity to the sediments. Cocolithiphoridæ were not present, or escaped any notice because of rarity.

Two forms whose origin is uncertain seem worthy of mention as contributing materials. One of these is a calcareous ovoid, very much the shape of an egg, of a white opaque appearance, usually ranging in size from 0.1 mm. to 0.3 mm. This is exactly similar in outward appearance to the oolites of the calcareous muds from the Florida-Bahama region,[1] but they show no concentric structure when examined in thin section under the microscope; their extreme rarity and non-association with chemically precipitated fine calcareous muds makes their origin seem different from the oolites in spite of the strong resemblance. As these forms exhibit no characteristic structure under the microscope, it is suggested that they may be coprolitic pellets, perhaps the excretion of echinoderms.

Very much more abundant are some tiny bodies of translucent calcium carbonate of irregular shape, yet always showing certain characteristics that make them easily recognized; on one side they show a smooth convex surface that includes commonly one-fourth to one-third of the surface area; the rest of the surface shows an irregularly faceted arrangement, the whole effect being that of a spherical segment or part of a spherical body, and occasionally one of the bodies does have a complete spherical or ovoid form. The material is distinctly translucent carbonate, with a prismatic structure evident when viewed under the microscope. In size they usually range from 0.05 to 0.1 mm. but occasionally exceed these dimensions. The origin of this material is uncertain; it was at first thought to be the cuttings of *Cliona* or other boring sponge, as very similar bodies of this origin are figured by Topsent,[2] but the uniformity of microstructure militates against such a view; the cuttings seemingly would come from various organisms and show a variety of microstructures. Another possible origin is that they are the polyhedral spicules of Astroscleridæ as described by Lister[3] and figured in The Cambridge Natural History, vol. 1, p. 194. In size, internal structure, and outward form they seem to fit the description of these polyhedra and will be so classed in this study.

[1] T. W. Vaughan. Corals and the formation of coral reefs. Smithsonian Rept. for 1917, pp. 216-220, plates 31, 32, and 33.

[2] The Cambridge Natural History, p. 219.

[3] Willey's Geological Results, Pt. IV, 1900, pp. 459

CAREFULLY STUDIED SAND FOR CORRELATION WITH CHEMICAL ANALYSIS.

Aua No. 4. Sand from Aua Reef, 50 feet from shore.

MEGASCOPIC DESCRIPTION.

A mottled light buff-colored sand, grains of coarse-sand grade predominate, though not well sorted, and showing a range of sizes from gravel several millimeters in diameter to fine sand, grains irregular in shape but with some rounding of corners, especially in finer sand sizes, sand of organic origin with less than 1 per cent inorganic. The organisms in order of abundance are algæ, coral, mollusks, crustacea, foraminifera, bryozoa, and others in less than 1 per cent of total.

Chemical analysis (Mr. Fairchild, of Geological Survey Laboratory).

Per cent soluble in ⅛ HCl boiled 3 minutes:

SiO_2	
$(AlFe)_2O_3$	0.22
CaO	51.85
MgO	2.31
CO_2	42.60
Ignition (less $CO)_2$	1.70
P_2O_5	

Insoluble:

SiO_2, $(AlFe)_2O_3$, CaO, MgO, Alkalies	0.45 per cent

Ocean salts 1.79 per cent.

Calculated:

$CaCO_3$	92.59 per cent
$MgCO_3$	4.85 per cent

TABLE 1.—*Detailed examination of grades. Aua No. 4.*

Grade.	Class.	Size.	P. ct. of total.	Composition (volume percentages based on count of 100 to 300 grains in each grade. Weight percentages appx. same.[1]
		mm.		
No. 0	Gravel	6 to 2	10.6	Coral 45%, Halimeda 13.97%, Corallinaceae 11.5%, mollusks 15.5%, crustacea 3%, Orbitolites 1.2%, Polytrema 1.1%, basalt 8.8%.
No. 1	Fn. gravel	2 to 1	14.7	Halimeda 35.9%, Corallinaceae 18.8%, coral 14.0%, mollusks 7.9%, crustacea 6.2%, Baculogypsina 5.8%, Amphistegina 3.5%, Polytrema 2.0%, Orbitolites 2.6%, bryozoa 0.8%, alcyonarian spicules 0.8%, Serpula 1.0%, Spirorbis 0.9%. Small fraction of 1% Gypsina, Calcarina, echinoid, basalt, feldspar.
No. 2	Crs. sand	1 to 5	32.0	Corallinaceae 31.6%, coral 27.3%, Halimeda 20.1%, crustacea 4.6%, mollusks 6.2%, Amphistegina 2.0%, Baculogypsina 0.9%, Polytrema 1.1%, Serpula 0.4%, Spirorbis 0.2%, alcyonarian spicules 0.7%, basalt 0.3%, olivine 0.7%. Small fraction of 1% Calcarina, Orbitolites, bryozoa.
No. 3	Med. sand	0.5 to 0.25	15.9	Coral 35.3%, Corallinaceae 28.3%, Halimeda 15.8%, crustacea 4.9%, mollusks 3.2%, bryozoa 3.5%, Amphistegina 1.9%, Baculogypsina 1.5%, alcyonarian spicules 0.8%, Serpula 1.9%, echinoid 1.0%, millepore 1.3%. Small fraction of 1%, olivine, basalt, olivine basalt, porphyry.
No. 4	Fn. sand	0.25 to 0.1	25.6	Coral 42.3%, Corallinaceae 21.8%, Halimeda 17.3%, mollusks 5.7%, crustacea 3.1%, Baculogypsina 2.5%, Nonionina 0.6%, bryozoa 1.4%, alcyonarian spicules 1.4%, Serpula 0.8%, Spirorbis 0.2%, echinoid 1.3%, ostracod 0 3%, olivine 0.6%. Small fraction of 1% calc. sponge spicules, miliolidae, Dentalium, basalt, Dactyloperas, Astroscleridae polyhedra.
No. 5	Very fn. sand	0.1 to 0.05	0.45	Coral 50.5%, Halimeda 20%, Corallinaceae 20.8%, mollusks 5.1%, crustacea 4.0%, Polytrema 2.1%, Baculogypsina 1.9%, miliolidæ 1.5%, bryozoa 1.3%, echinoid spines 2.8%, olivine 1.5%. Small fraction of 1% sponge spicules, ascidian spicules, ostracods, pteropods, basalt, volc. glass, magnetite.
No. 6	Silt	0.05 to 0.005	0.35	Finely comminuted fragments of the common organisms such as coral, algae and mollusks and the whole organism of minute forms such as miliolidae, foraminifera, sponge spicules, and ascidian spicules. Diatoms are rare and apparently no Cocolithiphoridæ. Inorganic constituents only 1 or 2%.
No. 7	Clay	0.005 to 0.0	0.45	Fine calc. particles and aggregates and colloidal aggregates, also much plant-fiber material. No aragonite needles are present or other material recognizable as a chemical precipitate.

[1] See correlation with chemical analysis.

CAREFULLY STUDIED SILT.

1919 No. 7.—From bottom at Mooring Buoy C, depth 28.5 fathoms.

MEGASCOPIC DESCRIPTION.

A very light gray silt, rather well sorted except for few large organic fragments. Residue from treatment with dilute HCl of brown color and consisting of siliceous spicules and inorganic rock material. Somewhat plastic when wet, forming a coherent chalk-like mass when dry.

Chemical analysis (Mr. Fairchild, of Geological Survey Chemical Laboratory).

Per cent soluble in ⅓ HCl boiled 3 minutes:		Insoluble:	
SiO_2	0.96	SiO_2	8.73
$(AlFe)_2O_3$	4.73	$(AlFe)_2O_3$	4.78
CaO	38.27	CaO	0.30
MgO	2.97	MgO	0.18
CO_2	32.00	Alkalies	1.91
Ignition (less CO_2)	5.40		
P_2O_5	0.19	Ocean salts	2.39 per cent
Calculated:			
$CaCO_3$	65.70 per cent		
$MgCO_3$	6.00 per cent		

TABLE 2.—*Detailed examination of grades. 1919, No. 7.*

Grade.	Class.	Size.	P. ct. of total.	Composition. (Volume percentage based on count of about 100 grains in each grade. Weight percentage appx. same.)
		mm.		
No. 1	Fn. gravel	2 to 1	0.3	Mollusks 74%, echinoid plates 18%, crustacea 3%, fine sand aggregates 5 %.
No. 2	Crs. sand	1 to 0.5	0.5	Mollusks 40.7%, aggregates of silt and clay 19.5%, cinder 10.0%, crustacea 6.4%, echinoid plates 6.0%, foraminifera 3.3%, Halimeda 2.9%, Corallinaceæ 2.2%, echinoid spines 2.9%, pteropods 2.0%, Dentalium 1.3%, bryozoa 0.9%, brachiopod(?) 0.7%, feldspar 1.1%.
No. 3	Med. sand	0.5 to 0.25	0.3	Mollusks 22.8%, aggregates of silt and clay 17.7%, cinder 10.1%, foraminifera 9.3%, Corallinaceæ 8.7%, Halimeda 8.2%, crustaceæ 6.7%, coral 3.1%, pteropod 1.3%, echinoid plates 1.4%, echinoid spines 1.5%, bryozoa 1.0%, Dentalium 1.0%, olivine 1.5%, pumice 1.1%, basalt 1.0%, felsitic rock 1.0%.
No. 4	Fn. sand	0.25 to 0.1	5.2	Aggregates of silt and clay size 39.9%, Halimeda 9.1%, mollusks 9.0%, foraminifera 4.2%, Corallinaceæ 3.5%, coral 3.5%, pteropods 3.8%, Dentalium 2.8%, crustacea 2.7%, echinoid plates 2.3%, echinoid spines 1.6%, bryozoa 2.5%, alcyonarian spicules 1.4%, ostracods 0.5%, inorganic 13.0%, including basalt, olivine, magnetite, cinder, volc. glass, feldspar.
No. 5	Very fn. sand	0.1 to 0.05	25.5	Coral 20.0%, Astroscleridæ polyhedra 16.7%, Halimeda 12.8%, ascidian spicules 9.0%, Corallinaceae 7.0%, foraminifera 9.0%, mollusks 6.4%, aggregate of silt and clay 5.5%, pteropods 3.9%, cinder 3.8%, Dentalium 1.9%, ostracods 1.3%, calcareous sponge spicules 1.0%, oval siliceous sponge spicules 1.0%, feldspar 0.6%. Fraction of 1%, bryozoa, echinoid fragments, crustacea.
No. 6	Silt	0.05 to 0.005	56.9	Inorganic 66%, including feldspar, olivine, cinder, basalt, trachyte, volcanic glass, magnetite. Organic 35%, including siliceous sponge spicules 5%, cellulose plant fibers 5%, calc. organisms as in grade No. 5, 25%.
No. 7	Clay	0.005 to 0.00	11.4	Fine particles of calcareous and inorganic materials and aggregates of these with colloidal matter.

CORRELATION OF PETROGRAPHIC ANALYSIS WITH CHEMICAL ANALYSIS.

The results of a careful analysis of a reef sand, Aua No. 4, to determine the constituent organisms, and the correlation of the composition of these various organisms with the mass composition as determined by chemical analysis, is represented in table 3. Because of the many minor inaccuracies and indeterminate factors in such a correlation, so great care in some details was not attempted as in a similar study made by Doctor Goldman[1] and the fact that the agreement in the correlation is as close as or closer than in his attempt indicates that no greater refinements were worth while, in this case at least. The percentage composition of each grade was determined by taking a sample of 60 to 250 grains, the number taken for any grade depending approximately on the relative quantitative importance of that grade, and after estimating the volume of an individual grain as compared with a unit volume, the nature of the constituent organism was determined either by inspection of external form and appearance or by crushing and examining the microscopic structure. After a preliminary study of the microscopic structure of known materials, the quantity of indeterminate material becomes negligible.

The greatest inaccuracies in this study probably depend on three factors. First, the number of grains taken as an average composition of each grade could give only an approximation, but inasmuch as the composition is not so heterogeneous as might be supposed the estimate should not be far off on this account. A second and perhaps more serious error may be introduced by the method of estimation of grain volumes, by comparison with a selected unit volume, but in this the personal factor was lessened by occasional corroboration of estimates by another person. The third source of error rests in the adoption of the volume percentages to equivalent weight percentages in most cases. The error so introduced seemed at first unallowable, but was permitted because on determining the specific gravity of the various components no very great difference was found between the porous coral materials and the various algæ, which are the important constituents. In the case of the molluscan material the specific gravity was distinctly greater than the average for the others, and so a correction was made for weight percentages in this case only.

With these weight percentages of the constituent organisms and the percentage of calcium to magnesium carbonate of the various organisms obtained from the work of Clarke and Wheeler,[2] the total percentage of calcium to magnesium carbonate was calculated as shown in table 3, the calculated percentage of magnesium carbonate, 5.24

[1] M. I. Goldman. Papers from the Department of Marine Biology of the Carnegie Institution of Washington, vol. IX, Pub. 16, 213, pp. 249, 1918.

[2] Clarke and Wheeler. The inorganic constituents of marine invertebrates. U. S. Geol. Survey Prof. Paper 102, 1917.

TABLE 3.—*Correlation of petrographic and chemical analyses. Aua No. 4.*

Organism.	Gravel.	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	Silt.	Clay.	Total.	$MgCO_3$,[a] p. ct.	$CaCO_3$, p. ct.	$MgCO_3$, total.	$CaCO_3$, total.
Mollusk	1.1	1.0	2.1	0.5	1.4	.....	.....	.....	[b]1.6 [b]4.6	0	100	.....	[b]6.40
Halimeda	2.1	5.6	6.1	2.4	4.2	0.1	.....	.....	20.5	0	100	...	20.50
Corallinacae	1.7	2.0	9.6	4.3	5.3	.1	.....	.....	23.0	17	83	0.91	19.09
Coral	6.7	1.9	8.3	5.3	10.6	.2	.....	.....	33.0	0.05	99.5	.16	32.84
Baculogypsina	0.0	0.8	0.3	0.2	0.6	.....	.....	.....	1.9	11	89	.21	1.69
Amphistegina	.....	0.5	0.6	0.3	.....	.....	.....	.....	1.4	10	90	.14	1.26
Crustacea	0.2	0.9	1.4	0.7	0.8	.....	.....	.....	4.0	8	92	.32	3.68
Echinoid	.....	.....	0.8	0.2	0.3	.....	.....	.....	1.3	10	90	.13	1.17
Foraminifera	.....	0.1	0.2	0.1	0.1	.....	.....	.....	0.5	8	92	.04	0.46
Basalt	1.3	.....	0.1	.....	.....	.....	.....	.....	1.4	.....	.....	.00	.00
Bryozoa	.....	0.1	.....	0.5	0.3	.....	.....	.....	0.9	5	95	.04	9.86
Ostracod	.....	.....	.....	.....	0.1	.....	.....	.....	0.1	.....	.....	.00	0.10
Alcyonaria	.....	0.1	0.2	0.1	0.3	.....	.....	.....	0.7	13	87	.09	0.61
Polytrema	0.1	0.2	0.3	.....	.....	.....	.....	.....	0.6	11	89	.07	0.53
Orbitolites	0.6	0.3	.....	.....	.....	.....	.....	.....	0.9	11	89	.10	0.80
Serpula	.....	0.1	0.1	0.3	0.2	.....	.....	.....	0.7	5	95	.03	0.67
Spirorbis	.....	0.1	0.1	.....	0.1	.....	.....	.....	0.3	.....	.....	.....	0.30
Millepore	.....	.....	.....	0.2	.....	.....	.....	.....	0.2	.....	.....	.....	0.20
Olivine	.....	.....	0.2	.....	0.1	.....	.....	.....	[0.3 [98.0	.....	.....	.....	.....
Total	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.24	91.16
Calculated from chemical analysis	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	4.85	92.59

[a] The percentages of magnesium to calcium carbonate here used represent an approximate value, rather than an average, obtained from the analyses of Clarke and Wheeler.
[b] Correction to 6.4 for the higher specific gravity of mollusk.

per cent, being greater than the determined percentage by chemical analysis, 4.85 per cent. The reason for this discrepancy is not obvious, but is perhaps no greater than might be expected with the methods employed.

DISCUSSION OF MECHANICAL ANALYSES.

An examination of the mechanical analyses fails to show any marked agreement with such laws of transportation and sorting as those postulated by Udden.[1] This non-conformity is probably due in large part to the local origin of the sediments here studied or their production almost *in situ* and without the prolonged transportation that would impress the characteristics generally recognized. Another factor that may be of some importance is that a considerable proportion of the material is not comminuted, but remains the size of the original contributing element, and such materials, when not sufficiently reworked, will show sizes depending, to this extent, on the contributing materials at the particular place.

Points of non-agreement include the lack of a secondary maximum in most of the samples, and where such secondary maximum is present it does not represent a coarser grade, but on the contrary a finer grade. Even the generalization that the grade of greatest quantity is one of the mean sizes, or intermediate grades, is not borne out in some of the reef sands, such as Aua Nos. 2, 3, 8, 9, 10, 11. In these cases the maximum is the coarsest grade present. (See fig. 1.)

[1] J. A. Udden. Mechanical compilation of clastic sediments. Bull. G. S. A., vol. 25, pp. 665, 1914.

TABLE 4.—*Mechanical analyses of samples from Pago Pago Harbor, Samoa (by U. S. Bureau of Soils).*

Number.	Description of locality.	Fine gravel, 4 to 2 mm.	Very coarse sand, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.005	Clay, 0.005 to 0 mm.
Aua No. 1...	Beach above high tide	0.86	6.45	23.0	30.7	38.4	0.0	0.0	0.6
Aua No. 2...	Beach at low tide.....	51.9	40.8	5.6	0.25	0.3	0.5	0.15	0.7
Aua No. 3...	10 feet from shore....	30.2	23.4	27.6	9.5	7.9	0.1	0.1	1.2
Aua No. 4...	50 feet from shore....	15.0	13.9	30.4	15.1	24.4	0.4	0.3	0.4
Aua No. 5...	100 feet from shore...	17.1	12.3	30.0	14.1	24.7	0.9	0.2	0.9
Aua No. 6...	200 feet from shore...	11.5	20.6	46.5	9.4	10.3	0.3	0.3	0.8
Aua No. 7...	300 feet from shore...	23.4	10.1	32.0	12.7	19.5	0.8	0.3	1.0
Aua No. 8...	400 feet from shore...	29.8	15.4	22.6	8.4	18.6	2.3	1.6	1.1
Aua No. 9...	500 feet from shore...	34.2	12.4	24.9	9.8	14.8	1.5	0.9	1.6
Aua No. 10..	600 feet from shore...	34.8	16.2	27.1	8.3	9.8	1.0	0.9	1.8
Aua No. 11..	700 feet from shore...	44.0	23.1	17.1	4.5	8.3	0.8	0.6	1.6
Aua No. 20..	Off reef front (Sand collected in barrels.)	0.0	2.2	17.4	21.2	53.9	3.8	1.0	1.0
Aua No. 21..	Off reef front (Sand collected in barrels.)	0.0	2.2	17.4	17.4	56.8	3.9	1.2	1.4
Aua No. 22..	Off reef front (Sand collected in barrels.)	0.0	0.5	4.5	5.8	75.0	10.6	1.7	1.6
Aua No. 23..	Off reef front (Sand collected in barrels.)	0.0	1.2	13.6	15.2	61.3	4.7	2.0	2.1
Aua No. 24..	Off reef front (Sand collected in barrels.)	0.0	0.7	5.3	5.8	73.9	10.8	2.2	1.4
Nuuli A.....	Center of Nuuli lagoon	0.0	5.3	25.8	13.6	41.9	8.4	1.4	3.7
Nuuli B.....	Near shore Nuuli lagoon.	0.0	4.3	25.2	17.3	42.8	5.7	4.5	0.1
1919 No. 1..	Off mooring buoy A, depth 16.5 fath.	0.0	0.0	0.05	0.07	2.4	18.1	57.9	22.0
1919 No. 2..	600 feet off Utelei Reef	20.0	5.4	8.0	2.7	11.9	13.8	30.8	7.4
1919 No. 3..	Bottom of Utelei boring 65′ deep, 200 feet from shore.	0.0	0.0	0.0	0.0	4.7	20.2	52.9	21.8
1919 No. 4..	At mooring buoy B, depth 23.5 fath.	2.5	0.2	0.6	0.6	4.5	12.3	69.2	10.0
1919 No. 5..	Midway between Breaker Point and Point Distress, depth 28 fath.	0.0	0.0	0.1	0.1	7.2	49.8	36.3	6.7
1919 No. 6..	Off Oceanic S. S. mooring buoy, depth 26 fath.	0.0	0.3	1.0	0.6	2.3	14.8	67.9	13.4
1919 No. 7..	At mooring buoy C, depth 28.5 fath.	0.0	0.3	0.4	0.3	3.2	24.1	59.9	11.9
1919 No. 8..	Midway between Blacklock's Wharf and inner end of harbor, depth 3.5 fath.	0.0	0.2	7.9	11.0	26.9	24.1	24.6	5.8
1919 No. 9..	East of Whale Rock buoy, depth 36.5 fath.	0.0	0.0	0.1	0.2	11.2	46.8	34.0	7.9
1917 No. 0..	Inner end of harbor, off village, depth 12 feet.	0.0	0.0	0.3	0.2	2.9	45.3	45.6	6.1
1917 No. 1..	Off Blacklock's wharf, depth 30 ft.	0.0	0.0	0.0	0.0	4.2	7.2	74.2	14.8
1917 No. 2..	Off mooring buoy B, depth 138 feet.	0.0	0.0	0.0	0.0	2.5	13.6	68.4	15.9
1917 No. 3..	Off Goat Island, depth 164 feet.	0.0	0.2	0.8	0.4	2.0	25.9	63.2	7.4
1917 No. 4..	East of Whale Rock black buoy, depth 213 feet.	0.0	0.1	0.4	0.5	12.5	42.4	35.6	8.4
1917 No. 5..	Silt from coral live car, 100 feet from mouth of Pago Pago brook.	0.0	0.0	0.7	1.5	43.9	40.9	10.9	2.8

However, the analyses do show definite relations to transporting factors usually. The most obvious of these relations is seen in the silts which cover the protected inner bend of the harbor, where wave action is very much less pronounced and the process of silting may become operative; whereas in the harbor entrance and so far back as the turn in the bay washing is pronounced, due to the strong wave action, and the finer material is carried back into the more quiet waters or out into the deeper waters off the island and a fine sand is

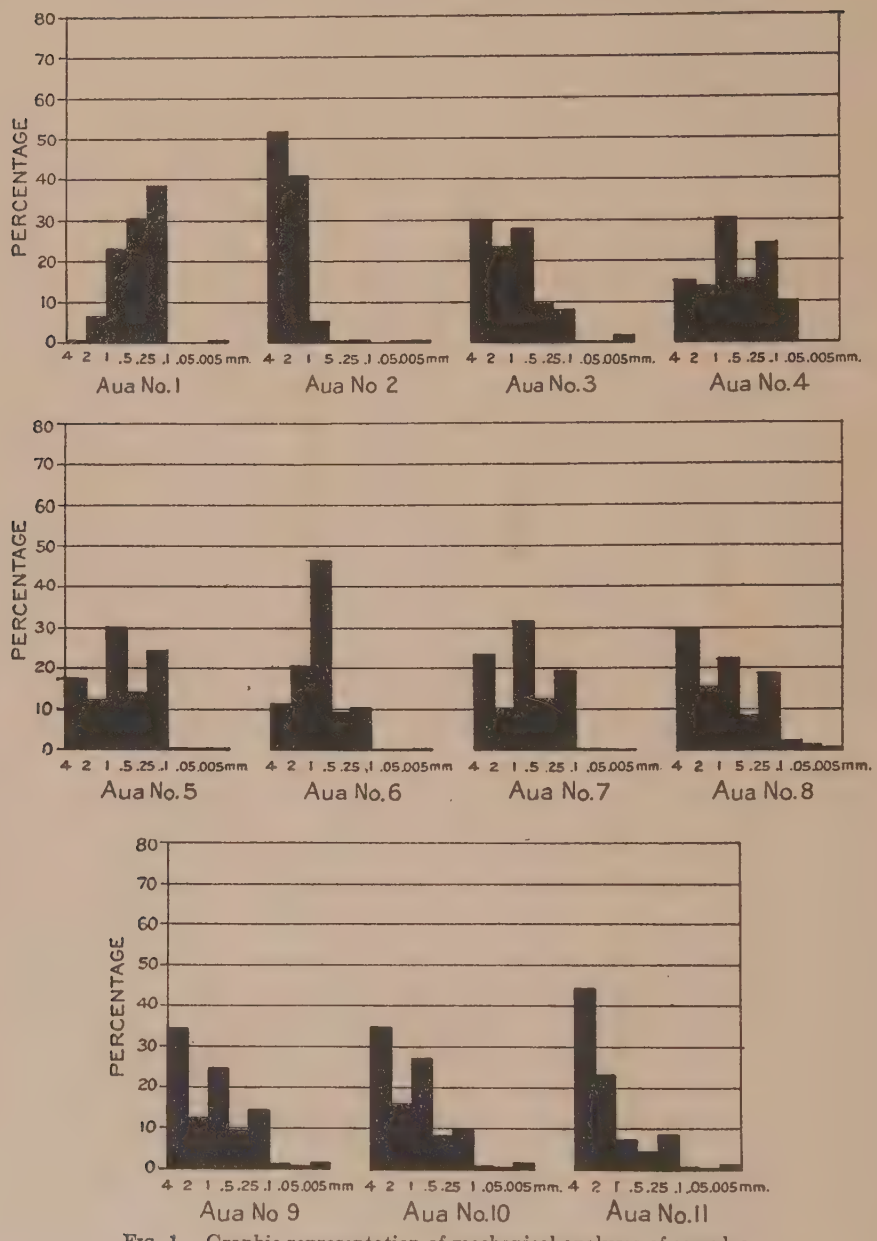

FIG. 1.—Graphic representation of mechanical analyses of samples.

here the bottom material, in spite of a greater depth than that of the silted region farther in the harbor.

In the Aua Reef sands (see fig. 1) a very striking difference is seen between No. 1, which is above high tide, and No. 2, which is at low tide,

the former being less well sorted and of a much finer size, but the interpretation of this difference does not seem certain. Nos. 4, 5, 6, and 7 are rather similar, having a maximum in grade No. 2, and with secondary maxima, all show a considerable range of sizes and not good sorting. Nos. 3, 8, 9, 10, and 11 are also of a common type and not very dissimilar to the others, except that the maximum is in the coarsest or gravel size. Nos. 20, 21, 22, 23, and 24 represent a sand that was collected in barrels off the reef to determine the rate of removal of sand in this manner (see fig. 2). Most of it was trans-

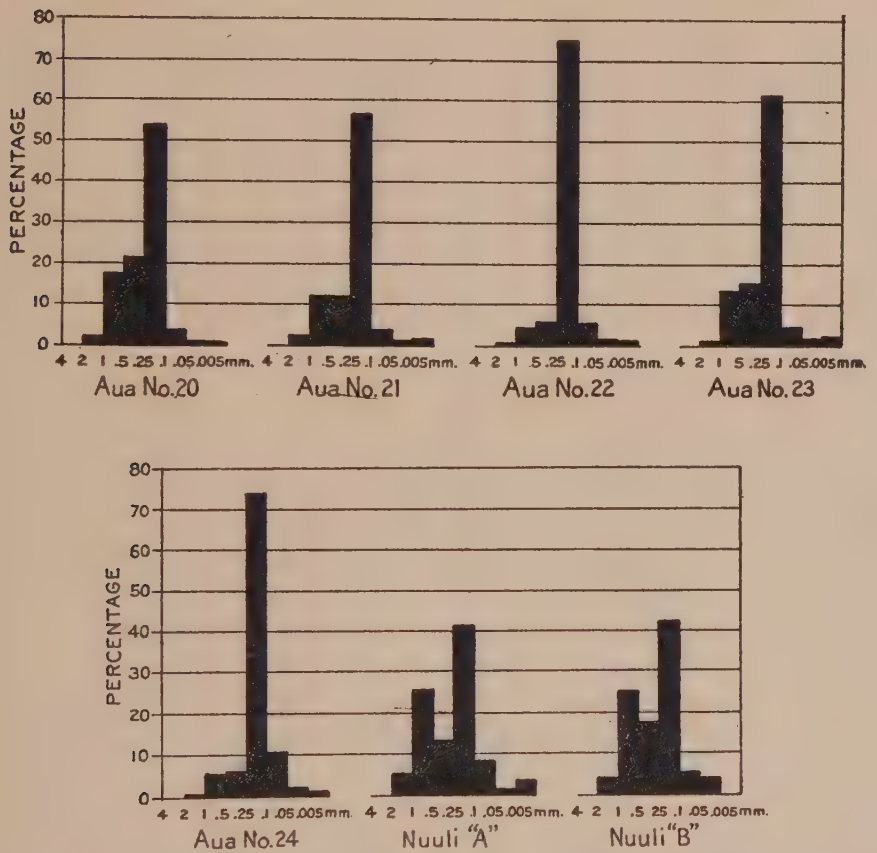

FIG. 2.—Graphic representation of mechanical analyses of samples.

ported during a gale of about 10 hours with a wind velocity of 40 miles per hour at its maximum.[1] They are very similar, all showing a very pronounced maximum in the No. 4 grade. Some relation of this sand being removed from the reef flat to the sands on the reef flat was sought but was not seen.

[1] A. G. Mayor. Carnegie Inst. Wash. Pub. 340, pp. 27-36.

Nos. 1 and 2 of the 1917 series and Nos. 1 and 3 of the 1919 series form an allied group of silts showing a strong maximum in the silt grade amounting to from 50 to 75 per cent of the total and with the next largest grade in the clay size. Resembling these in the silt grade, strong maxima are Nos. 4, 6, and 7 of 1919 series and No. 3 of 1917 series, but these samples differ in having the next largest grade in the very fine sand. (See figs. 3 and 4.)

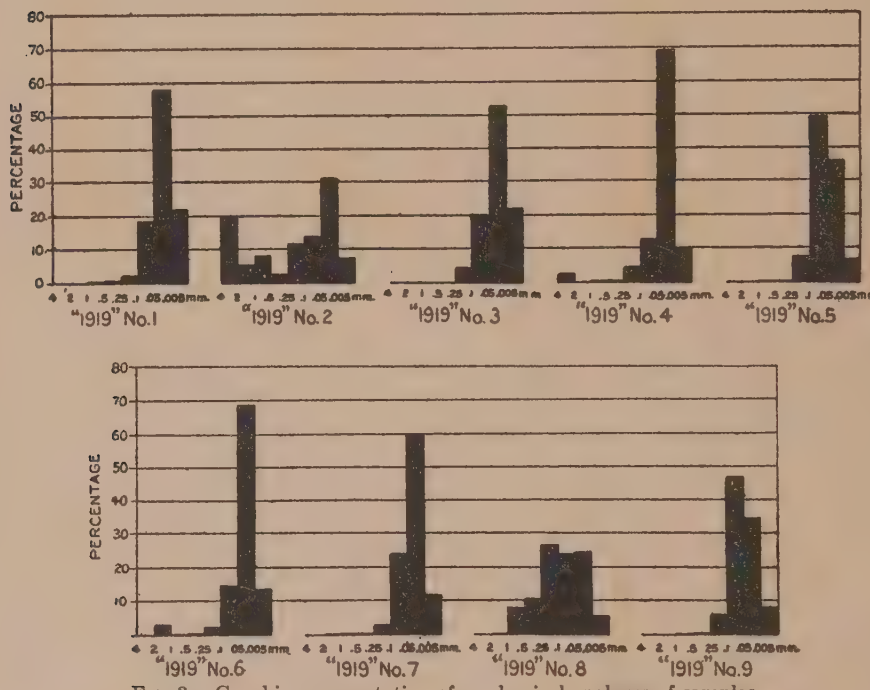

FIG. 3.—Graphic representation of mechanical analyses of samples.

Nos. 5 and 9 of the 1919 series and No. 4 of the 1917 series represent a type in which the maximum is in the very fine sand grade with the next largest grade of silt size. These are a type produced in the region of strong wave action with the resultant washing and removal of the greater quantity of the silt size, as previously described.

Nos. 0 and 5 of the 1917 series and No. 8 of the 1919 series represent sediments deposited in relatively quiet marine waters by mountain streams, largely affected at periods of torrential flow, an additional though subordinate factor being the material contributed by marine organisms.

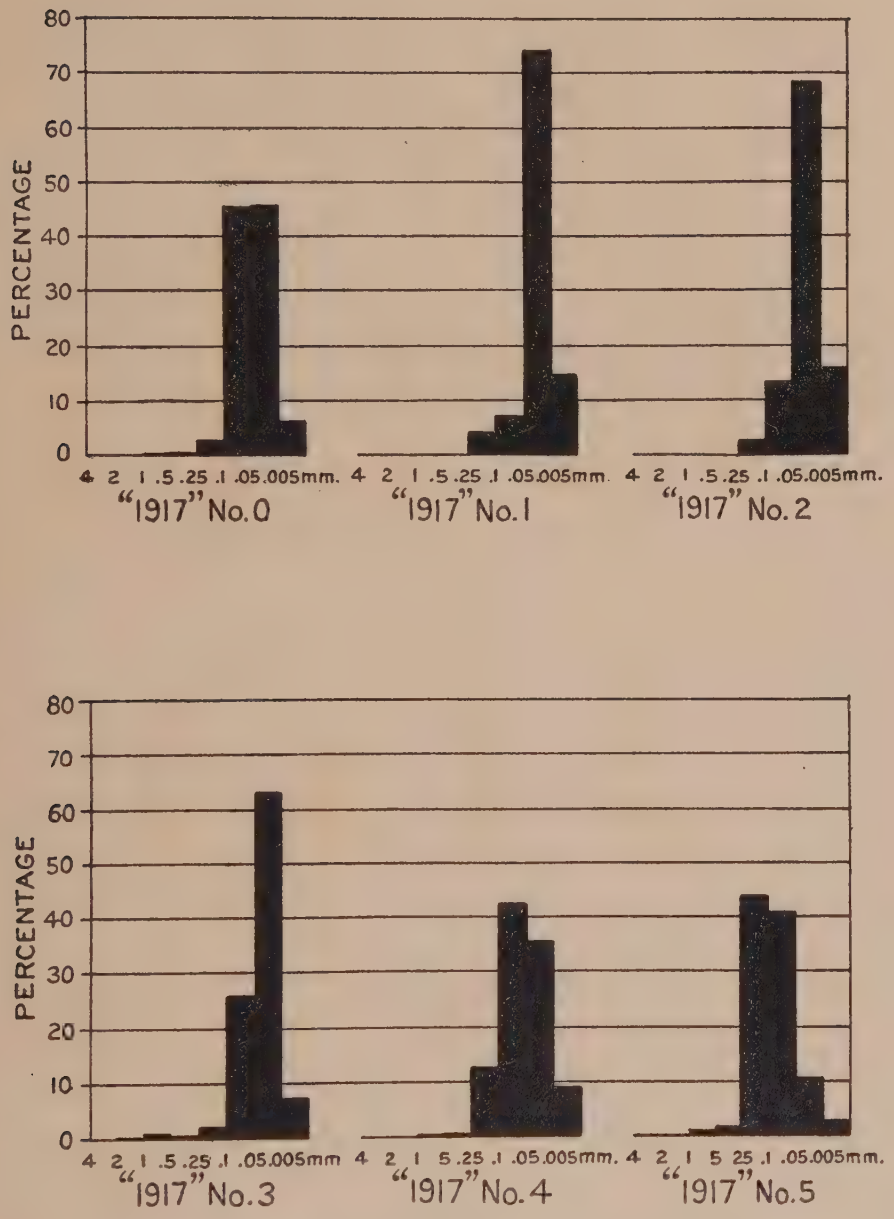

FIG. 4.—Graphic representation of mechanical analyses of samples.

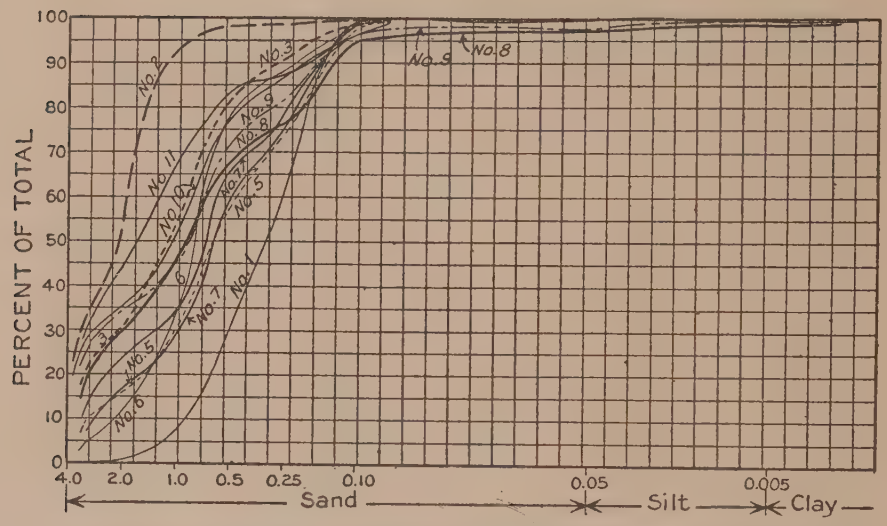

FIG. 5.—Graphic representation of cumulative percentages of mechanical analysis of Aua Reef samples. Diameter of grades in millimeters.

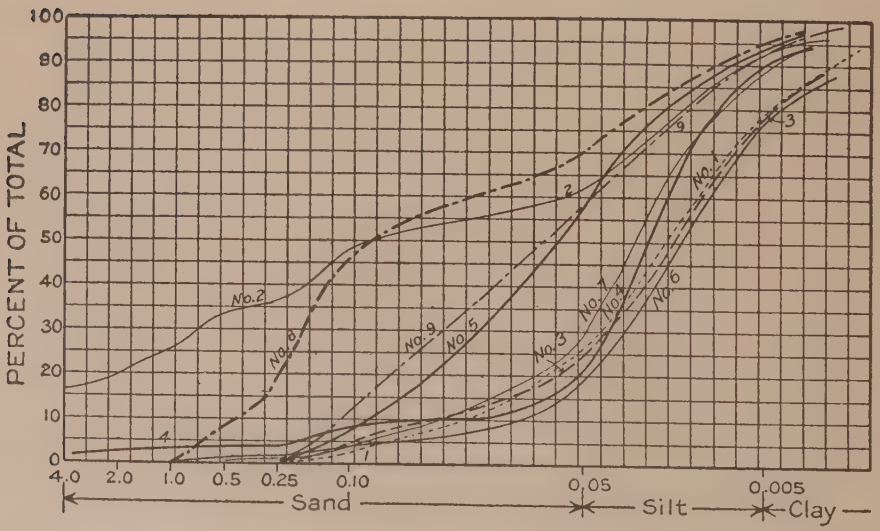

FIG. 6.—Graphic representation of cumulative percentages of mechanical analysis of 1919 series samples. Diameter of grades in millimeters.

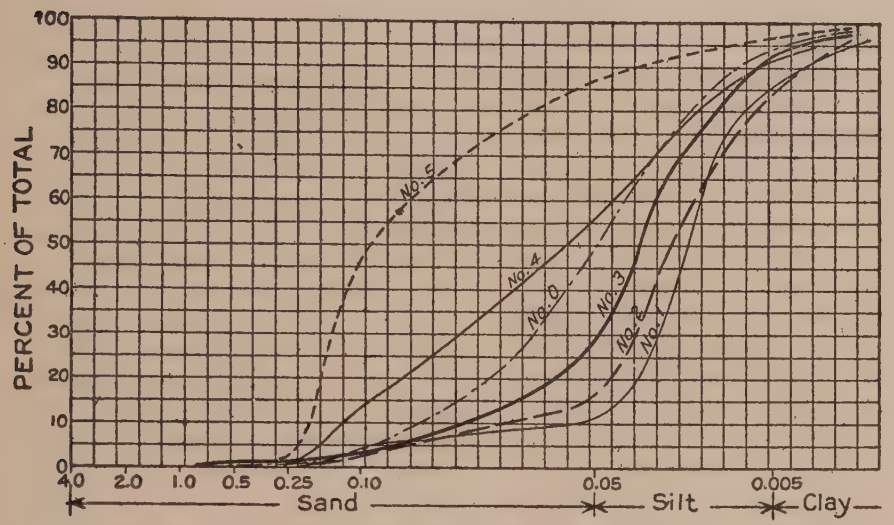

FIG. 7.—Graphic representation of cumulative percentages of mechanical analysis of 1917 series samples. Diameter of grades in millimeters.

DISCUSSION OF CHEMICAL ANALYSES.

The chemical analyses made by Mr. J. G. Fairchild, of the Geological Survey chemical laboratories, are presented in tables 5 and 6.

In table 5 the $CaCO_3$ and $MgCO_3$ are presented as calculated from the percentages of CaO and MgO, assuming a sufficient quantity of CO_2, which is nearly correct except in Aua 12 and Aua 13. In these two samples, the excess water on ignition seemed to indicate the presence of basic magnesium carbonate, and only sufficient MgO was combined as $MgCO_3$ to satisfy all the CO_2 present. These two samples are unlike the other reef samples in consisting of a few large fragments of Corallinaceæ rather than the usual detrital organic sand of heterogeneous composition.

The sands from the Aua Reef are a very pure carbonate material with only a fraction of 1 to 2 per cent of inorganic constituents. These sands also show a rather uniform ratio of calcium carbonate to magnesium carbonate, with no evidence of a concentration of magnesium carbonate, under special conditions or a tendency toward dolomitization, except in the two samples mentioned above. The average composition of Aua No. 1 to 11, inclusive, shows 92.52 per cent $CaCO_3$ and 4.30 per cent $MgCO_3$. A correlation of this composition with the composition of the component organisms has been presented on the case of the Aua No. 4 sample, and the other reef sands are very similar. The magnesium is contributed in large part by the Corallinaceæ present in the sands.

In table 6 the $MgCO_3$ was not calculated, as the indications are that a considerable portion of the MgO is present in these samples as a basic carbonate. In these samples there is not enough CO_2 to combine with the MgO after deducting the necessary quantity of CO_2

to combine with CaO, and the excess of H_2O represented in the loss on ignition seems to partly belong with this MgO as such a basic compound.

The soluble SiO_2 is obtained by one evaporation only of the filtered HCl solution of the sample. This quantity is in many cases a little less than 1 per cent. In other cases, showing much higher quantities of the soluble SiO_2, the sample has been leached with water and then ignited, in order to obtain the combined loss of water and carbon dioxide. This ignition has increased the solubility of the silicates; also, in such cases, the sample was too small for a separate determination of carbon dioxide.

It is probable that the treatment of the samples in 1 to 3 HCl has been somewhat too severe. This treatment has extracted, in the case of sample No. 5 (1917), some calcium and magnesium silicate. In nearly all the cases considerable iron and aluminum oxides have been dissolved that without doubt are a part of the insoluble clay constituents. Finally, no interpretation is given to the soluble SiO_2, which may be in part colloidal, such as opaline silica, or it may have been derived from partial solution of the silicates. If the latter, then, a small quantity of the CaO and MgO are combined with SiO_2.

Determination of CaO and MgO was made of boring samples from Aua Reef, 512 feet from shore, as follows:

	CaO	MgO	CO_2	$CaCO_3$	$MgCO_3$
No. A (depth 65 feet)	48	4	41	86	8
No. B (depth 152 to 156 feet)	47	4	40	84	8

These samples show a higher ratio of $MgCO_3$ to $CaCO_3$ than any of the surface samples, though consisting of the same organic constituents, and seem to indicate an enrichment in magnesia or tendency toward dolomitization in the buried part of the reef.

TABLE 5.—*Chemical analyses of samples from Pago Pago Harbor, Samoa.*

[By J. G. Fairchild, Chemical Laboratory, U. S. Geological Survey.]

Soluble in 1–3 HCl.[a]	Aua No. 1.	Aua No. 2.	Aua No. 3.	Aua No. 4.	Aua No. 5.	Aua No. 6.	Aua No. 7.	Aua No. 8.	Aua No. 9.	Aua No. 10.	Aua No. 11.	Aua No. 12.	Aua No. 13.
$(Al-Fe)_2O_3$	0.35	0.38	0.35	0.22	0.10	0.10	0.20	0.20	0.11	0.11	0.11	0.10	0.10
CaO	51.68	51.38	51.10	51.85	51.90	51.60	52.18	52.10	52.00	52.15	52.02	43.72	42.86
MgO	1.86	2.13	2.13	2.31	1.98	2.29	2.04	1.86	2.30	1.84	1.90	8.53	8.06
CO_2	42.42	41.90	42.05	42.60	42.91	43.15	42.50	42.95	41.95	43.25	42.65	39.25	41.00
Ignition[b]	1.98	1.90	3.11	1.70	1.94	1.60	2.25	1.50	2.80	1.45	2.59	7.75	7.00
Insoluble	1.15	2.19	1.44	0.45	0.35	0.27	0.27	0.30	0.22	0.23	0.22	0.12	0.07
Total	99.44	99.88	100.18	99.13	99.18	99.01	99.44	99.01	99.38	99.03	99.49	99.47	99.09
Calculated per cent of carbonates:[c]													
$CaCO_3$	92.25	91.70	91.20	92.65	92.70	92.15	93.12	93.00	92.90	93.10	92.95	78.08	76.52
$MgCO_3$	3.89	4.45	4.45	4.83	4.14	4.79	4.27	3.89	4.81	3.85	3.97	9.37	14.05

[a] Corrected for ocean salts present. [b] Less CO_2.

[c] Analysis indicates some basic magnesium carbonate, only sufficient MgO combined as $MgCO_3$ to satisfy all the CO_2.

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RÉSUMÉ.

The examination of the bottom samples from the tropical embayment of Pago Pago Harbor, Tutuila, shows three distinct types of sediments which are being deposited, with lateral gradation from one to the other.

Upon the reef flats and on the reef slopes immediately adjacent thereto, a calcarenyte is forming, that has been commonly called a coral sand but might more accurately be termed an algo-coral sand, as the calcareous algæ are usually more important than the corals as constituents. In some of these calcarenytes the coral may exceed the algæ but not by a very large amount, and such sand might be termed a coralgal sand. Besides these two major constituents of the calcarenyte, mollusk fragments are present in considerable percentages and an appreciable quantity consists in crustacean fragments and foraminifera, with many less abundant calcareous organisms, such as echinoid plates and spines and bryozoa. This calcarenyte is a very pure carbonate material, consisting of about 92 per cent calcium carbonate and 4 or 5 per cent magnesium carbonate, with only 1 per cent or so of inorganic rock material intermixed. The magnesium carbonate present is almost all supplied by algæ of the group of Corallinaceæ, which are very abundant and contain about 17 per cent of magnesium carbonate in their composition as an average. The mechanical analyses of these sands shows them to be very poorly sorted, with a wide range in sizes, but only a negligible quantity of materials as fine as or finer than the very fine sand grade; materials of these finer grades are carried off the reefs by the strong wave action into deeper water.

TABLE 6.—*Chemical analyses of samples from Pago Pago Harbor, Samoa.*

[By J. G. Fairchild, Chemical Laboratory, U. S. Geological Survey.]

	Nuuli A	Nuuli B	1919, No. 1.	1919, No. 2.	1919, No. 3.	1919, No. 4.	1919, No. 5.	1919, No. 6.	1919, No. 7.	1919, No. 8.	1919, No. 9.	1917, No. 0.	1917, No. 1.	1917, No. 2.	1917, No. 3.	1917, No. 4.	1917, No. 5.
Soluble:																	
SiO_2	0.57	0.79	6.68	3.36	5.25	6.01	2.26	6.10	0.96	2.22	3.36	0.97	0.99	0.98	0.86	0.60	1.10
$(Al\text{-}Fe)_2O_3$	1.39	2.05	10.06	3.05	8.35	7.94	2.29	10.14	4.73	5.62	3.16	14.72	13.42	6.41	2.84	1.47	16.30
CaO	49.11	46.30	19.28	46.60	32.90	33.80	46.34	31.00	38.27	12.50	45.38	3.80	9.75	36.19	41.57	45.72	2.01
MgO	2.92	2.50	1.82	2.39	2.47	2.72	2.89	2.72	2.97	1.07	2.79	2.03	1.85	2.70	2.63	2.65	2.73
CO_2	40.30	38.23	undet	38.45	26.90	undet	undet	25.29	32.00	undet	37.85	undet	undet	29.66	34.67	37.35	trace
P_2O_5	0.13	0.13	0.37	0.13	0.32	0.25	0.13	0.32	0.19	0.33	0.13	0.43	0.56	0.22	0.19	0.08	0.47
Ignition	2.10	3.17	29.20	3.55	4.80	35.80	42.50	8.21	5.40	22.30	4.17	[a]	undet	6.79	3.93	[b]6.40	9.47
Insoluble:																	
SiO_2	1.27	3.56	14.57	1.46	9.92	5.87	2.32	8.07	8.73	22.36	2.23	32.55	30.22	9.56	7.15	3.08	26.77
$(Al\text{-}Fe)_2O_3$	1.34	3.11	13.84		8.50	6.59		6.76	4.78	27.61		26.42	23.76	7.34	4.60		40.33
CaO	.....	.....	1.76	.....	.....	.....		.....	0.30	1.60	.....	1.15	.....	.....	.....	3.20	.....
MgO	.....	.....	1.10	.....	.....	.....		.....	0.18	2.76	.....	0.90	.....	.....	0.75		
Alkalies	.....	.....	undet	undet	.....	.....	undet	.....	1.91	undet	.....	1.58	.....	.....			
Total	99.13	99.84	98.68	98.99	99.41	98.98	98.93	98.61	100.42	98.37	99.07	[a]84.53	[a]80.55	99.85	99.19	100.55	99.18
$CaCO_3$	87.50	82.40	34.42	82.95	58.10	59.80	82.73	54.70	68.00	22.32	80.78	5.87	16.23	64.18	73.85	81.50	trace
$Ca_3P_2O_8$	0.28	0.28	0.81	0.28	0.70	0.55	0.28	0.70	0.41	0.74	0.28	0.94	1.22	0.47	0.41	0.17	1.03

[a] Contains much organic matter.

[b] Analysis indicates some basic magnesium carbonate.

In the deeper waters of the inner part of the harbor a calcareous silt or calcilutyte is being deposited which consists in a very heterogeneous mixture of calcareous organisms, many of which are planktonic or benthonic, with a much less important quantity of the calcareous algæ and corals. Molluscan material is one of the major constituents, as are foraminifera, pteropods, and various sponge and ascidian spicules. This calcilutyte has a considerable percentage of inorganic material consisting in large part of fine volcanic rock fragments washed in by the streams. There is also a large percentage of colloidal matter in these silts, being as high as 30 per cent in sample 1917 No. 3, resulting in considerable plasticity. The ratio of magnesium carbonate to calcium carbonate is higher than in the calcarenytes according to the chemical analyses, if all the soluble magnesia is calculated as the carbonate, which, as previously stated, seems unjustifiable. In the pure carbonate sands of the reef such an assumption is undoubtedly near the truth, but in these silts where there is a considerable quantity of inorganic material it is probable that some other magnesium compounds have been classed as carbonates and the actual ratio of magnesium carbonate to calcium carbonate is not greater than in the reef sands. The magnesian rich Corallinaceæ are very much less important in these silts than in the reef sands, but an increased proportion of imperforate foraminifera and crustaceans, especially ostracods, would about offset this loss, as they are also rich in magnesium carbonate. The sorting is very much better in the silts than in the reef sands, with a smaller range of sizes and a very much stronger maximum in the dominant grade, and rounding is inappreciable though rather marked in the reef sands near the strand line.

A third type of sediment consists of fine inorganic sand brought down by the mountain streams, being of very limited areal extent, and localized near the stream mouth. This material consists of small igneous rock fragments to a large extent, most of it fine basalts, trachytes, and volcanic glass, but with many grains of a single mineral, especially magnetite, olivine and feldspar being common also, but quartz apparently entirely absent. All the minerals are fresh and show no evidence of weathering. A small percentage of calcareous and siliceous organisms are intermixed with the inorganic sand. The material is not well sorted, and the grains show little evidence of rounding.

A fourth type, which is rather a combination of two of the other types, is the very fine sand in the deeper parts of the harbor nearer the mouth. This fine calcarenyte consists of the finer material carried out from the reef destruction intermixed with the numerous planktonic and benthonic organisms, such as largely contribute to the formation of the calcilutyte, previously described. In this rather

open part of the harbor most of the silt and clay size material is washed out, so that it lacks the high colloidal content of the calcilutytes of the inner part of the harbor. It is a very pure carbonate sand, well sorted, but with the maximum not so marked in one grade but rather distributed in two grades.

These sands are thus producing a result often noted in rocks so formed in the geological past. In the reefs the reef sands of coarse material are filling in the spaces between the growing corals and other sessile organisms, and are deposited on the slopes of the reefs to some extent. Farther down the slopes, or between slopes, the fine materials are deposited, probably with some stratification. On induration these calcareous sediments will supply evidence as to their origin by the high percentage of $CaCO_3$ compared to inorganic matter and by the fossil organisms. The several facies may be difficult of recognition, but the "coral" reef proper should be different from the sediments of the bay between the reefs, not only in the differences in organisms, but the non-reef material may show some stratification and a higher inorganic content. A tendency toward the change to a magnesian limestone, if not a dolomite, seems indicated by the higher percentage of $MgCO_3$ present in the core samples from depths of 65 and 152 feet in the Aua Reef boring.

COMPARISON WITH THE SEDIMENTS FROM THE BAHAMAS AND MURRAY ISLAND.

The calcarenytes from the reef flat of Pago Pago Harbor show a marked similarity to the reef sands from Murray Island, as described by T. W. Vaughan.[1] In both cases the sands are poorly sorted, with a large percentage of coarse sand and gravel and with negligible quantities of the very fine sand, silt, and clay. The absence of fine materials is explained in each case as due to the removal of such material by the strong currents in the shallow waters rather than to solution.

In both sands the corals and calcareous algæ make up about three-fourths of the total composition, with the corals predominating in some and the algæ in others, in both localities; and even in this variation there is a correspondence, for nearer shore in each case it is the algæ which are most important, while farther out on the reef the corals assume the major rôle. The percentage of mollusk is somewhat larger in the Murray Island sands and the percentage of crustacea much less than in those from Pago Pago Harbor, and there seems to be a greater variety of forms in the latter locality, though many of them are of minor importance quantitatively.

[1] T. W. Vaughan. Some shoal-water bottom samples from Murray Island, Australia, and comparison of them with samples from Florida and the Bahamas. Carnegie Inst. Wash. Pub. No. 213, p. 239.

The chemical analyses of the reef sands from the two localities are also similar, showing very pure carbonate materials with about 5 per cent of magnesium carbonate, though the tendency to a concentration of magnesia in the beach sand is not found in the Pago Pago Harbor samples.

As shown by Doctor Vaughan, the samples from the Bahamas and Florida of the reef sands are very similar to those from Murray Island in chemical composition and in organic constituents. The most striking difference is that the Bahama reef sands are of a finer size than those from Murray Island or Pago Pago Harbor, but they show the great range of sizes and poor sorting characteristic of the other reef sands. Thus these sands from the three widely separated localities show a striking similarity.

With the facts of chemical precipitation of calcium carbonate at hand, as a result of the work of Drew and Vaughan, careful consideration was given to the possibility of such a process being operative in the embayment of Pago Pago. No such fine calcareous mud is being deposited in this case, however, and the small percentage of fine silt and clay size material present in these sediments consists of the comminuted fragments of calcareous organisms, inorganic clay, and colloidal matter, rather than the needles of aragonite, which compose the chemical precipitate of the Bahama Banks.

That there is no such precipitation of carbonates can not be affirmed, but it certainly is of no quantitative importance; and as there is rather a special combination of physical conditions in the Bahama case, it seems probable that the process does not take place except under some such combination of conditions.

TABLE 7.—*Temperature records, Pago Pago, Tutuila. 1902 to 1912 and 1912 to 1920.*
[From report of Lieut. F. C. Nyland.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1902	81.3	80.6	81.3	81.7	81.9	76.7	75.4	77.1	76.0	76.6	81.3	81.9	79.5
1903	82.6	83.2	85.9	79.3	80.7	78.7	78.4	78.5	79.3	80.1	80.1	82.3	80.7
1904	80.6	82.3	83.3	80.1	80.3	79.6	79.1	79.6	79.6	81.3	82.3	81.6	80.8
1905	81.4	81.8	82.6	79.8	80.1	78.3	79.4	80.3	80.1	80.6	81.3	82.3	80.6
1906	83.2	82.5	85.4	80.2	81.6	79.5	81.2	81.1	79.9	79.8	80.3	83.1	81.4
1907	82.0	83.1	81.3	81.1	80.2	79.9	80.0	79.6	79.9	79.4	80.1	82.4	80.7
1908	83.2	82.5	82.3	81.7	79.6	79.9	81.1	79.9	79.6	80.2	81.2	83.1	81.1
1909	82.5	81.9	81.4	80.3	81.1	80.2	81.2	80.6	77.2	81.3	83.3	81.6	80.0
1910	83.1	80.6	80.2	79.4	80.2	78.4	78.6	80.3	79.3	79.9	82.1	82.3	80.3
1911	81.6	81.4	83.4	81.2	81.6	80.3	76.8	79.6	78.4	80.5	80.8	81.2	80.5
1912	82.7	82.5	82.1	80.6	80.3	79.8	79.3	80.1	77.5	79.8	81.6	82.4	80.7
1914	86.1	83.1	83.0	80.7	82.4	79.6	81.1	80.4	81.6	80.5	82.7	83.4	82.0
1915	83.4	81.6	81.9	81.7	80.7	78.5	79.8	78.7	81.2	79.8	79.9	80.8	80.1
1916	81.2	81.4	81.9	80.5	80.9	80.0	80.7	80.4	80.8	80.2	83.2	83.6	81.2
1917	83.5	82.3	83.1	82.5	82.4	81.3	81.9	81.2	82.1	81.6	82.5	82.6	82.1
1918	83.0	82.9	79.9	81.7	81.6	82.4	81.9	82.3	82.6	83.3	84.3	85.8	82.6
1919	84.7	84.7	85.7	85.7	83.4	83.6	82.6	80.4	78.9	78.6	81.6	93.3	82.8
1920	81.1	83.3	82.6	81.3	82.1	80.4	80.4	78.4	78.4	77.7	79.5	79.5	80.5
Average	82.6	82.3	82.6	81.1	81.2	79.8	79.9	79.9	79.5	80.3	81.6	82.4	80.9

TABLE 8.—*Rainfall record, United States Naval Station, Pago Pago, Tutuila, 1900-1920.*

[Inches.]

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Total.
1900	16.4	18.3	41.1	13.1	11.3	0.1	4.5	3.0	5.9	9.8	19.6	24.1	167.2
1901	21.5	29.0	17.1	9.4	15.1	3.5	10.4	6.2	21.6	21.2	18.4	3.9	177.3
1902	12.9	37.9	5.2	14.2	5.7	25.2	3.0	4.4	5.0	8.7	11.0	14.4	147.6
1903	21.9	24.9	12.7	26.0	12.1	12.5	16.6	11.2	10.3	19.9	20.4	10.8	199.3
1904	21.2	27.2	10.5	21.3	8.3	11.0	10.5	13.1	10.9	9.3	21.9	10.9	176.1
1905	21.8	12.1	15.5	16.0	3.5	10.3	7.5	10.6	1.7	8.7	12.3	10.1	130.1
1906	5.3	9.9	18.0	14.1	18.6	14.7	6.1	7.4	12.7	13.2	13.2	13.0	47.2
1907	19.2	21.2	11.3	26.1	13.1	32.0	12.5	5.0	11.1	23.7	29.0	17.9	222.1
1908	32.6	48.3	39.5	13.7	23.8	9.2	8.2	10.3	28.5	16.1	41.7	12.4	284.4
1909	16.1	15.1	11.6	13.8	15.5	9.8	3.6	3.6	8.1	11.8	19.9	16.2	145.1
1910	20.7	10.2	28.1	19.7	9.5	16.3	3.4	11.6	17.8	15.1	15.2	30.9	198.5
1911	18.8	30.2	19.3	11.7	12.3	5.2	5.2	2.3	5.0	12.3	9.4	18.1	149.8
1912	15.1	7.7	22.3	31.9	30.8	12.1	4.5	3.4	14.7	10.4	20.0	22.4	195.4
1913	27.7	44.7	17.8	25.5	60.5	12.3	21.8	5.4	17.2	18.6	7.5	16.0	275.2
1914	4.0	20.4	14.7	18.1	9.4	19.5	10.7	20.4	38.9	49.2	16.1	19.2	250.6
1915	37.5	7.9	17.6	10.7	1.7	4.5	16.4	0.6	10.0	10.1	8.7	30.6	156.3
1916	14.5	28.6	9.1	12.2	14.0	12.1	9.6	10.6	11.0	18.9	26.5	39.0	206.1
1917	38.3	34.6	34.0	22.2	5.4	20.7	7.5	5.8	7.8	19.5	29.8	24.3	249.9
1918	15.1	43.1	17.9	10.9	7.6	8.7	38.3	6.7	5.8	7.4	15.0	30.4	206.9
1919	49.8	22.6	16.5	8.4	14.8	9.6	2.0	4.7	11.3	3.9	16.9	14.4	174.9
1920	14.7	13.4	21.6	28.7	12.7	49.2	8.5	18.8	8.6	26.4	31.1	23.4	257.1
Average	21.2	24.2	19.1	17.5	14.6	14.2	10.0	7.9	13.0	15.9	19.3	19.2	196.1

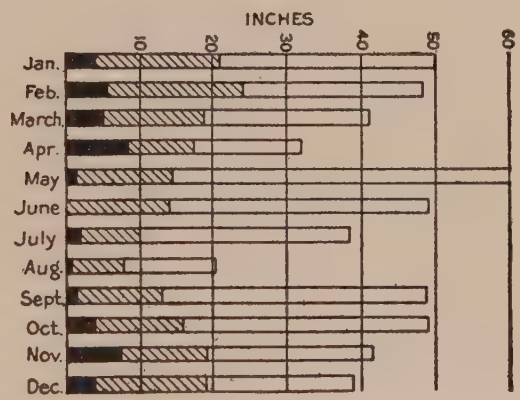

FIG. 8.—Rainfall at Pago Pago, Samoa. Highest, lowest, and average monthly amounts for years 1900 to 1920, inclusive. (From Monthly Weather Review, vol. 50, No. 1m, Jan. 1922.)

TABLE 9.

Sea-water from off Pago Pago Harbor, Samoa, analyzed by Prof. A. H. Phillips.		Sea-water from off Tortugas, Florida, analyzed by Dr. George Steiger.	
Ca	0.4366		0.4420
Mg	1.3512		1.3054
K	0.3715		0.4000
Na	11.0793		11.1957
Cl and Br	20.1704	Cl	20.0762
		Br	0.0644
SO_4	2.7138		2.7422
Total	36.1228		36.3516

TABLE 10.

Number and location.	Physical character and classification.	Summary composition, all grades.	Grade No. 1, fine gravel, 2.0 mm. to 1.0 mm.	Grade No. 2, coarse sand, 1.0 mm. to 0.5 mm.
1919 (1). Off mooring buoy A. depth 16.2 fathoms.	A gray silt, about 40% calcareous organisms, plastic evidently having considerable colloidal material; residue after solution with HCl is brown and largely inorganic. No rounding of grains except in aggregated masses, where it is the result of the analysis treatment.	Over 50% volcanic material, coral and algae not so dominant in the calcareous material as in that of the reef sands.	0.0% of total.	0.10% of total. Fine aggregates 50%, mollusks 20%, cinder 15%, feldspar 5%, cellulose material, crustacea, and other calcareous fragments 10%.
1919 (2). 600 feet off Utelei Reef, between Utelei and Aua, depth 29.5 fathoms.	A light gray silt, largely organic, very poorly sorted with many Halimeda fragments intermixed, nonplastic, chalk-like, small per cent of residue, after solution with HCl, of brown color, though consisting in large part of spicules and siliceous materials. No appreciable rounding of grains.	Largely of calcareous organic composition with coral and algae of subordinate importance, many fragments of Halimeda above 2.0 mm.	6.7% of total. Halimeda 80%, mollusks 8%, Amphistegina 5%, Corallinaceae 3%, coral 2%, Heterostegina 2%.	10.0% of total. Composition similar to Grade No. 1 but little less dominance of Halimeda and more coral, foraminifera, and crustacea. Rare echinoid spines, Spirorbis, Baculogypsina.
1919 (3). Bottom of Utelei Boring, 200 feet from shore, 65 to 68 feet from surface.	A light gray silt (darker than 1919, (2) at least 50% organic, plastic, and when dry forms a coherent mass. Residue from HCl treatment a light brown material largely inorganic.	Coral and algae, though important constituents, do not even together exceed the other organic constituents, as was the case in the reef sands.	0.0% of total.	0.1% of total. Rounded or discoidal fragment of aggregated finer materials, apparently so shaped in the shaking to disintegrate for sizing and so belonging to the finer grades.
1919 (4). Mooring buoy B, depth 23.5 fathoms.	A light gray silt, largely organic, somewhat plastic, HCl residue of brown color, consists of siliceous organisms and inorganic material. Some large cinder fragments up to 8 mm.	.....	0.2% of total. Fragments of cinder.	0.6% of total. Cinder 75%, remainder mollusk fragments.
1919 (5). Midway between Breaker Point and Point Distress, depth 28 fathoms.	A light gray, very fine sand, almost entirely organic, non-plastic and incoherent when dry. HCl residue of brown color consisting of siliceous organisms but more largely inorganic material. No appreciable rounding of grains.	A heterogeneous organic material with mollusks as important as coral or algae and many foraminifera and small spicules.	0.0% of total.	0.1% of total. Mollusks 40%, foraminifera 10%, crustacea 20%, feldspar 10%, fiber 10%, felsite 10%.

"Aggregates" is used to indicate aggregates of finer grades, largely silt and clay.

TABLE 10—*Continued.*

Grade No. 3, medium sand, 0.5 mm. to 0.25 mm.	Grade No. 4, fine sand, 0.25 mm. to 0.1 mm.	Grade No. 5, very fine sand, 0.1 mm. to 0.05 mm.	Grade No. 6, silt, 0.05 mm. to 0.005 mm.	Grade No. 7, clay, 0.005 mm. to 0.00 mm.
0.50 % of total. Fine aggregates 85 %, cinder 5 %, mollusks 5 %, crustacea, foraminifera, feldspar and algal fragments 5 %.	9.6 % of total. Fine aggregates 75 %, mollusks 10 %, cinder 5 %, misc. 10 %, including crustacea, foraminifera, coral, algae, echinoids, pteropods, few ostracods, and feldspars.	18.1 % of total. Inorganic 40 %, including volcanic glass, felsite, basalt, magnetite, feldspars, olivine, siliceous sponge spicules 5 %, coral 10 %, Halimeda 8 %, Corallinaceae 7 %, mollusks 6 %, Astroscleridae polyhedra 6 %, foraminifera 5 %, ascidian spicules 3 %, misc. 10 %, including echinoids, ostracods, pteropods, alcyonaria, holothuria, crustacea.	52.9 % of total. Inorganic 55 %, composition similar to Grade No. 5. Siliceous sponge spicules 5 %, calcareous organisms 40 % as in Grade No. 5.	19.3 % of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material.
3.4 % of total. Halimeda 50 %, coral 14 % Corallinaceae 8 %, mollusk 8 %, crustacea 6 %, foraminifera 5 %, amphistegina 3 %, echinoid 2 %, bryozoa 1 %, misc. 3 %, including Spirorbis, sponge spicules, olivine, and basalt.	14.9 % of total. Marked decrease in Halimeda with increase in Corallinaceae and foraminifera. Occasional alcyonarian spicules, pteropods and coprolitic pellets, small amount of olivine and basalt.	17.2 % of total. Halimeda in a comparatively insignificant percentage, many siliceous sponge spicules, pteropods, and foraminifera, also Astroscleridae polyhedra and ascidian spicules, some coprolitic pellets, and ostracods, only a fraction of 1 p. ct. inorganic.	38.5 % of total. About 10 % inorganic, including olivine, magnetite, volcanic glass, and feldspar. Organic composition similar to Grade No. 5 with addition of some diatoms.	9.3 % of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material. A very few aragonite needles possibly chemically precipitated.
0.4 % of total. Composition similar to grade No. 2 except for 2 or 3 % of Halimeda, coral, mollusks, and cellulose fragments.	9.4 % of total. About 50 % of the aggregates, otherwise composition is similar to Grade No. 5 with smaller per cent of Astroscleridae, polyhedra, and ascidian spicules.	20.2 % of tota Coral 15 %, Astroscleridae polyhedra 12 %, Halimeda 10 %, Corallinaceae 8 %, foraminifera 8 %, mollusks 5 %, crustacea 3 %, ascidian spicules 3 %, misc. 10 %, including sponge spicules, pteropods, ostracods, and echinoids. Inorganic 25 %, including basalt, olivine, volcanic glass, feldspar, magnetite, and few zircons and apatite crystals.	48.2 % of total. Composition similar to Grade No. 5, but larger percentage of spicules, especially Astroscleridae polyhedra, about 15 % inorganic. Similar to Grade No. 5.	21.8 % of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material.
0.9 % of total. Cinder 40 %, aggregates of fine grades 35 %, misc. 25 % including mollusks, feldspar, Baculogypsina, Corallinaceae and crustacea.	9.1 % of total. Inorganic 30 %, largely cinder but some feldspar and volcanic glass, aggregates 50 %, misc. 20 %, including mollusks, foraminifera, pteropods, crustacea, echinoids, Corallinaceae, and few ostracods.	21 % of total. Aggregates 30 %, coral 16 %, Halimeda 10 %, Astroscleridae 10 %, foraminifera 7 %, mollusks 8 %, Corallinaceae 6 %, cinder 3 %, echinoids 2 %, bryozoa 1 %, ostracods 1 %, siliceous sponge spicules, 1 %, rock material 8 %, misc. 3 %, including alcyonarian and sponge spicules and ascidian spicules.	62.6 % of total. About 90 % organic similar to that of Grade No. 5. Inorganic largely cinder, basalt, feldspar, olivine, and volcanic glass.	5.4 % of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material.
0.1 % of total. Mollusk 65 %, foraminifera 13 %, crustacea 12 %, echinoid 3 %, Halimeda 3 %, olivine 1 %, feldspar 1 %, ostracods 1 %.	7.2 % of total. Mollusk 20 %, coral 16 %, Halimeda 12 %, foraminifera 12 %, Corallinaceae 8 %, crustacea 6 %, bryozoa 5 %, pteropods 4 %, sponge spicules 2 %, alcyonaria 2 %, ostracods 2 %, echinoids 1 %, inorganic 10 %, including olivine, magnetite, feldspar, and basalt.	49.8 % of total. Halimeda 15 %, foraminifera 15 %, coral 10 %, mollusks 8 %, Astroscleridae polyhedra 15 %, ascidian spicules 5 %, crustacea 5 %, pteropods 5 %, bryozoa 2 %, alcyonaria 3 %, ostracods 2 %, inorganic 5 %.	36.3 % of total. Composition similar to Grade No. 5 but with increased proportion of various spicules.	6.7 % of total. More inorganic and cellulose material than in the silt grade, and more fragments approaching silt size than the usual very fine clay material.

TABLE 10—*Continued.*

Number and location.	Physical character and classification.	Summary composition, all grades.	Grade No. 1, fine gravel, 2.0 mm. to 1.0 mm.	Grade No. 2, coarse sand, 1.0 mm. to 0.5 mm.
1919 (6). Off Oceanic S.S. mooring buoy, depth 22 fathoms.	A light gray silt like 1919 (4), perhaps 50% organic, plastic when moist and when dry clay forms a coherent mass. HCl residue of brown color, largely of inorganic materials.	Coral a very minor constituent, and algae less than mollusk.	0.3% of total. Mollusks 30%, cinder 40%, Halimeda 15%, crustacea 10%, Baculogypsina 5%.	1.0% of total. Cinder 35%, Halimeda 17%, mollusks 14%, crustacea 6%, Corallinaceae 7%, coral 4%, magnetite 4%, foraminifera 2%, echinoid 2%, Baculogypsina 1%, inorganic 7%, including basalt, pumice, and olivine.
1919 (7). Mooring buoy C, depth 28.5 fathoms.	A very light gray silt, largely of organic composition, with some large organic fragments, somewhat plastic when wet, when dry forming a coherent, chalk-like mass. Brown inorganic residue.	.....	0.3% of total.	0.5% of total.
1919 (8). Sta. O on map of harbor, midway between Blacklock's wharf and inner end of harbor, depth 3.5 fathoms.	A mottled dark-gray, fine sand, largely inorganic, but with many organic fragments, up to several mm., non-plastic and incoherent when dry, poorly sorted.	Largely an inorganic material, algae most important of calcareous organisms.	0.2% of total. Halimeda 33%, mollusk 22%, crustacea 15%, foraminifera 20%, basalt 5%, Corallinaceae 5%.	7.9% of total. Halimeda 22%, mollusks 16%, Baculogypsina 9%, Corallinaceae 6%, coral 2%, bryozoa 1%, volcanic rock 33%, volcanic glass 7%, olivine 2%, feldspar 1%, fraction of 1% echinoid, alcyonaria, and foraminifera.
1919 (9). East of Whale Rock buoy, depth 36.5 fathoms.	A very light-gray fine sand, almost entirely organic, non-plastic and only slightly coherent when dry.	Algae perhaps most important constituent, with considerable percentage of mollusks, coral, and foraminifera.	0.0% of total.	0.1% of total. Fine aggregate 52%, mollusks 19%, foraminifera 5%, crustacea 7%, Corallinaceae 3%, coral 1%, echinoid 1%, sponge spicules 1%, bryozoa 1%, feldspar 2%, cinder 1%, basalt 1%, plant fiber 5%.

TABLE 10—*Continued.*

Grade No. 3, medium sand, 0.25 mm. to 0.1 mm.	Grade No. 4, fine sand, 0.25 mm. to 0.1 mm.	Grade No. 5, very fine sand, 0.1 mm. to 0.05 mm.	Grade No. 6, silt, 0.05 mm. to 0.005 mm.	Grade No. 7, 0.005 mm. clay, to 0.00 mm.
0.7 % of total. Composition similar to Grade No. 2, except in increase in magnetite and less coral, cinder, and about 10% of fine aggregated material.	5.9 % of total. Fine aggregates 61 %, mollusks 13 %, foraminifera 4 %, crustacea 4 %, Halimeda 3%, echinoids 3%, cinder 3 %. Corallinaceae 2 %, ostracod 2%, coral 1 %, pteropods 1 %, olivine 1 %, magnetite 1 %, basalt 1 %.	19.8 % of total. Composition similar to Grade No. 4 except only 25 % of aggregates and an increased proportion of the smaller whole organisms. Also some ascidian spicules.	61.9 % of total. Composition similar to Grade No. 5 but without the aggregates, and about 25 % inorganic, 5 % siliceous organisms.	10.7 % of total. Very fine calcareous and inorganic particles and aggregates or these with colloidal material.
0.3 % of total.	5.2 % of total.	25.5 % of total.	56.9 % of total.	11.4 % of total.
11.0 % of total. Composition similar to Grade No. 2, except inorganic amounts to about 60 %.	26.9 % of total. Halimeda 15 %, mollusks 5%, foraminifera 3 %, Corallinaceae 2 %, crustacea 1 %, coral 1 %, ostracods 1 %, alcyonaria 1 %, igneous rock 10 %, magnetite 3 %, ilmenite 1 %. Rare zircon and biotite.	24.1 % of total. Volcanic glass 37%, igneous rock 30%, magnetite 8%, mineral fragments, as in Grade No. 4, 5 %; calcareous organisms, as in Grade No. 4, 20 %.	24.6 % of total. About 40 % finely comminuted calcareous organisms such as foraminifera, algae, mollusks, also sponge spicules, polyhedra ascidian spicules, few per cent of siliceous monaxons, 60 % inorganic as in Grade No. 5.	5.8 % of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material.
0.2 % of total. Composition similar to Grade No. 2, except less than 5 % aggregates and more foraminifera.	11.2 % of total. Mollusks 18 %, foraminifera 15 %, Corallinaceae 13 %, coral 13 %, Halimeda 10 %, crustacea 6 %, bryozoa 4 %, pteropod 4 %, ostracods 4 %, echinoids 2 %, calcareous sponge spicules 2 %, Serpula 1 %, alcyonaria 1 %, olivine 1 %, basalt 3 %, feldspar 1 %, volcanic glass 1 %.	46.8 % of total. Composition similar to Grade No. 4 except for considerable percentage of Astroscleridae polyhedra, ascidian and siliceous sponge spicules.	34.0 % of total. Composition similar to Grade No. 5, with increased proportion of spicules and finer whole organisms. About 50 % inorganic.	7.9 % of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material. Largely inorganic.

TABLE 10—*Continued.*

Number and location.	Physical character and classification.	Summary composition, all grades.	Grade No. 0, gravel, 2.0 mm.	Grade No. 1, fine gravel, 2.0 to 1.0 mm.	Grade No. 2, coarse sand, 1.0 to 0.5 mm.
Aua No. 1. Beach above high tide, Aua Reef line.	Mottled light buff sand, medium to fine sand dominant but with wide range of sizes, distinct rounding of grain, and surface with porcelain-like gloss.	Organic constituents largely coral and algae but considerable p. ct. of Amphistegina and Baculogypsina.	0.9% of total. Halimeda 40%, coral 20%, mollusks 20%, mis. 20%, including Corallinaceae, echinoid plates, and basalt.	6.4% of total. Halimeda 35%, corallinaceae 16%, coral 14%, Amphistegina 7%, Baculogypsina 7%, crustacacea 5%, echinoid spines 3%, basalt 3%.	23% of total. Halimeda less dominant, being exceeded by coral. Relative increase in Corallinaceae and mollusks present in small quantities are alcyonarian spicules, bryozoa, worm tubes, and olivine crystals.
Aua No. 2. Beach at low tide, Aua Reef line.	Similar in color and composition to No. 1, but size is dominantly a gravel, shows considerable attrition and rounding of corners though seldom sphericity.	Algae make up almost 50% of total, coral abundant.	51.9% of total. Corals 35%, Halimeda 20%, mollusks 20%, misc. 25%, including Lithothamnium, crustaceans, basalt, etc.	40.8% of total. Similar composition to Grade No. 2, but increased proportion of Baculogypsina, no alcyonarian spicules or bryozoa. About 1% inorganic, basalt, and pumice fragments.	5.6% of total. Halimeda 30.8%, corals 21%, Corallinaceae 18.3%, mollusks 5.4%, crustacea 4.7%, Baculogypsina 7.4%, echinoid spine 5.1%, Amphistegina 2.7%, echinoid plates 1.4%, basalt 1.6%, Polytrema 0.9%, bryozoa 0.6%, also pumice, alcyonarian spicules, Spirorbis, Calcarina, orbitolites, and olivine.
Aua No. 3. Aua Reef line, 10 feet from shore.	Similar in color and composition to beach sands but less well sorted, showing sizes from fine sand to gravel, rounding less than in beach sand, also Baculogypsina, for example, retaining the stellar projections.	Algae constitute about 50% of total, coral very much less important.	30.2% of total. Coral 40%, mollusks 15%, Halimeda 15%, misc. 30%, including Corallinaceae, echinoid, crustaceans, basalt.	23.4% of total. Corallinaceae 34.2%, Halimeda 22.5%, coral 14.8%, mollusk 8.7%, Baculogypsina 7.3%, crustacea 6.4%, Amphistegina 2.5%, Serpula 1.9%, Orbitolites 1.6%, also echinoid plates and spines, Polytrema, Calcarina, and basalt.	27.6% of total. Composition similar to Grade No. 1 but with the addition of some ostracods, bryozoa, alcyonaria spicules, pteropods, and olivine.
Aua No. 4. Aua Reef line, 50 feet from shore.	Buff to grayish white sand, larger ratio of fine material than in No. 3 though still with same range in size. Attrition unimportant.	See special description.			
Aua No. 5. Aua Reef line, 100 feet from shore.	Similar in color and composition to No. 4, size of grains a very fine sand to gravel but with a great dominance of the fine materials. Attrition very slight.	Algae almost 50% of total, coral abundant.	17.1% of total. Halimeda 33%, coral 33%, mollusks 12%, Corallinaceae 8%, misc. 14% including echinoid fragments, Orbitolites, Serpula, and basalt.	12.3% of total. Composition similar to Grade No. 2 but with more Halimeda, Baculogypsina, and Amphistegina, and corresponding reduction of p. ct. of algae and coral. No inorganic material present, and no Spirorbis, ostracods, Alcyonaria, Orbitolites, as in Grade No. 2.	30.0% of total. Corallinaceae 30%, coral 24%, Halimeda 15.4%, mollusks 10.7%, crustacea 7.4%, Baculogypsina 2.6%, echinoid spines 1.0%, Serpula 1.5%, Polytrema 1.8%, foraminifera 2.0%, Amphistegina 1.2%, alcyonarian spicules 1.0%, ostracods 0.3%, also olivine, bryozoa, Spirorbis, Orbitolites, and Calcarina.
Aua No. 6. Aua Reef line, 200 feet from shore.	Similar to No. 5, but with a greater relative abundance of coarse and medium sands.	Algae dominant but with coral more nearly equal in quantity.	11.5% of total. Halimeda 50%, coral 5%, mollusks 15%, misc. 20%, including Orbitolites, crustaceans, Corallinaceae.	20.6% of total. Dominance of coral and Corallinaceae less marked than in Grade No. 2 with increase in Halimeda, Baculogypsina and Amphistegina. No alcyonaria, echinoids, or bryozoa as in Grade No. 2.	46.5% of total. Coral 37.1%, Corallinaceae 25.4%, Halimeda 14.2%, mollusks 13.3%, crustacea 7.1%, Amphistegina 1.9%, Baculogypsina 1.1%, also bryozoa, Spirorbis, Serpula, alcyonarian spicule, echinoids, polytrema, Orbitolites, Calcarina, Gypsina, olivine.

The word coral is used in these tables for Madreporia only; the Alcyonaria are listed Alcyonaria.

TABLE 10—*Continued.*

Grade No. 3, medium sand, 0.5 to 0.25 mm.	Grade No. 4, fine sand, 0.25 to 0.1 mm.	Grade No. 5, very fine sand, 0.1 to 0.05 mm.	Grade No. 6, silt, 0.05 to 0.005 mm.	Grade No. 7, clay, 0.005 to 0.000 mm.
30.7% of total. Composition similar to Grade No. 2 but less algal material and increase in proportion of Amphistegina and Baculogypsina.	38.4% of total. Similar to Grade No. 3, but with addition of few p. ct. of volcanic glass, olivine, and magnetite.	0.01% of total. About 50% volcanic rock material, remainder similar to Grade No. 4.	0.01% of total. Dominantly volcanic rock, many plant fibers, some calc. and siliceous sponge spicules and comminuted calcareous tests.	0.6% of total. Fine particles of calc. and inorganic material and aggregates of these with colloidal material.
0.25% of total. Composition similar to Grade No. 2 but with addition of some small foraminifera, olivine, and basalt.	0.3% of total. Similar to Grade No. 3, but with more small foraminifera and ostracods and some pteropods. Inorganic about 2%, including basalt, felsite, volcanic glass, magnetite, feldspar, chlorite, olivine, also 1% of plant fiber.	0.05% of total. Similar to Grade No. 4, with addition of sponge spicules and ascidian spicules. About 10% inorganic similar to Grade No. 4, with occasional zircon and tourmaline.	0.05% of total. Many small foraminifera, some diatoms, and the comminuted fragments of other calcareous organisms only small p. ct. of inorganic material.	0.7% of total. Fine calcareous particles and some ovoids larger than average that are probably sponge or ascidian spicules.
9.5% of total. Composition similar to Grade No. 2.	7.9% of total. Composition similar to Grade No. 3.	0.1% of total. Composition similar to Grade No. 4, except for several p. ct. of inorganic material, much of it being magnetite, also volcanic glass and chlorite.	0.1% of total. Similar to Grade No. 5, but with more small foraminifera, some diatoms, calcareous and siliceous sponge spicules, and small amount of plant fiber material.	1.2% of total. Fine calcareous particles and aggregates. Much plant-fiber material.
14.1% of total. About similar to grade No. 2, but with addition of Dentalium, calc. sponge spicules, Miliolidae, pteropods.	24.7% of total. Similar to Grade No. 3, but with proportion of small organisms greater than in coarser sands, also obsidian, basalt, magnetite, few coprolite pellets.	0.9% of total. Composition similar to Grade No. 4, inorganic material less than 1%. One zircon crystal, some ascidian spicules	0.2% of total. Composition similar to Grade No. 5 with addition of some siliceous sponge spicules, Astroscleridae polyhedra, few diatoms, and some plant fibers.	0.9% of total. Fine calcareous particles and aggregates.
9.4% of total. Composition similar to Grade No. 2, also some Miliolidae, foraminifera.	10.3% of total. Similar to Grade No. 3, plus some ostracods, few sponge spicules, about 1% inorganic, largely olivine, some basalt and feldspars.	0.3% of total. Similar to Grade No. 4, but fewer foraminfera, some ascidian spicules, Astroscleridae polyhedra, inorganic 2 or 3%, largely feldspars and olivine, some magnetite, occasional zircon.	0.3% of total. Similar to Grade No. 5, with addition of siliceous sponge spicules, some cellulose plant fiber.	0.8% of total. Fine calcareous particles and aggregates and some ovoids larger than average, that are probably sponge or ascidian spicules.

TABLE 10—*Continued.*

Number and location.	Physical character and classification.	Summary composition, all grades.	Grade No. 0, gravel, 2.0 mm.	Grade No. 1, fine gravel, 2.0 to 1.0 mm.	Grade No. 2, coarse sand, 1.0 to 0.5 mm.
Aua No. 7. Aua Reef line, 300 feet from shore.	Similar to No. 6.	Coral perhaps as abundant as the algae in this sand.	23.4% of total. Halimeda 45%, coral 15%, mollusks 15%, misc. 25%, including orbitolites, crustacea, corallinaceae, and echinoids.	10.1% of total. Much greater percentage of Halimeda, Amphistegina, Baculogypsina, and mollusks, with less coral than in Grade No. 2, no inorganic material.	32% of total. Coral 47.4%, Corallinaceae 30.4%, Halimeda 9.7%, mollusks 4.7%, crustacea 2.8%, Amphistegina 1.5%, Baculogypsina 1.1%, echinoid spines 1.5%, also Calcarina, Polytrema, echinoid plates, Spirorbis, and few olivine crystals.
Aua No. 8. Aua Reef line, 400 feet from shore.	Grayish white sand of extreme variations in size from very fine sand and silt to gravel of coral origin. Gravel and coarse sand dominant, very little evidence of attrition.	Coral dominant but with large percentage of calcareous algae.	29.8% of total. Coral 50%, Halimeda 25%, mollusks 10%, mis. 15%, including Corallinaceae, orbitolites, crustacea, and echinoids.	15.4% of total. Composition similar to Grade No. 2 but less coral, with more Halimeda, Amphistegina, Baculogypsina, and none of the rare constituents of Grade No. 2. No inorganic matter.	22.6% of total. Coral 38.0%, Corallinacae 24.5%, Halimeda 13.7%, mollusk 9.1%, crustacea 3.9%, echinoid spines 3.7%, Amphistegina 2.6%, Baculogypsina 1.1%, Alcyonarian spicules 1.5% Polytrema 1.1%. Also echinoid plates, Serpula, bryozoa, orbitolites, Calcarina, Spirorbis.
Aua No. 9. Aua Reef line, 500 feet from shore.	Very similar to Aua No. 8.	Algae and coral the two dominant constituents of the sand.	34.2% of total. Coral 35%, Halimeda 25%, mollusks 15%, misc. 25%, including Corallinaceae, crustacea, echinoid spines, orbitolites, Gypsina.	12.4% of total. Much greater proportion of Halimeda than in Grade No. 2, also more mollusks and crustacea, with less Corallinaceae and coral. No bryozoa or alcyonaria.	24.9% of total. Corallinaceae 35%, coral 28.4%, Halimeda 10.9%, mollusks 7.3%, crustaceae 5.9%, Amphistegina 3.4%, bryozoa 1.1%, Polytrema 0.8%, Serpula 1.5%, Orbitolites 1.0%, Baculogypsina 1.7%, echinoid spines 1.8%, also Calcarina, Spirorbis, Alcyonarian spicules, echinoid plate. No inorganic material.
Aua No. 10. Aua Reef line, 600 feet from shore.	Very similar to Aua No. 9.	Algae about 50% of total with coral important constituent but much less than algae.	34.8% of total. Halimeda 60%, coral 25%, mollusks 5%, misc. 10%, including Corallinaceae, crustacea, echinoid spines.	16.2% of total. Composition similar to Grade No. 2 but with greater proportion of Halimeda, mollusk, Amphistegina, Baculogypsina. No bryozoa nor rare constituents of grade No. 2.	27.1% of total.; Corallinaceae, Halimeda 23.0%, coral 17.5%, mollusks 5.6%, crustacea 5.5%, Amphystegina 2.9%, Miliolidae 2.6%, Polytrema 2.2%, Baculogypsina 2.1%, bryozoa 1 3%, echinoid spines 1.7%, Spirorbis 1.4%, Serpula 1.0%. Also Calcarina, ostracods, Alcyonarian spicules.
Aua No. 11. Aua Reef line, 700 feet from shore.	Large coral fragments form 74% of the sample, remainder similar to No. 10.	Algae and coral are dominant constituents.	44.05% of total. Halimeda 65%, coral 10%, mollusks 10%, misc. 15%, including Corallinaceae, Polytrema, echinoid spine, crustacea.	23.1% of total. Composition similar to Grade No. 2, but with greater proportion of Baculogypsina, mollusks, and crustacea and lesser proportion of coral.	17.1% of total. Halimeda 26.7%, coral 25.3%, Corallinaceae 23.2%, mollusk 8.9%, crustacea 3.7%, Amphistegina 3.3%, Baculogypsina 1.9%, bryozoa 2.1%, echinoid spines 1.8%, Polytrema 2.6%. Rare orbitolites and olivine.

TABLE 10—*Continued.*

Grade No. 3, medium sand, 0.5 to 0.25 mm.	Grade No. 4, fine sand, 0.25 to 0.1 mm.	Grade No. 5, very fine sand, 0.1 to 0.05 mm.	Grade No. 6, silt, 0.05 to 0.005 mm.	Grade No. 7, clay, 0.005 to 0.000 mm.
12.7% of total. Similar to Grade No. 2 plus some Miliolidae, foraminfera, some olivine, and basalt crystals.	19.5% of total. Similar to Grade No. 3 with the addition of ostracods, more foraminifera, pteropods, sponge spicules, and a fraction of 1% of olivine.	0.8% of total. Similar to Grade No. 4, also ascidian spicules, Astroscleridae polyhedra and a fraction of 1% of magnetite and basalt.	0.3% of total. Similar to Grade No. 5, with a few diatoms, only 1 or 2% inorganic.	1.0% of total. Fine calcareous particles and aggregates and some ovoids that are larger than the average and are probably sponge or ascidian spicules.
8.4% of total. Similar composition to Grade No. 2 plus some smaller foraminifera, few ostracods, and Dentalium. Inorganic small fraction of 1%, largely olivine.	18.6% of total. Similar to Grade No. 3 with increased proportion of foraminifera and ostracods, also some calcareous sponge spicules. Inorganic as in Grade 3.	2.3% of total. Similar to Grade No. 4, plus many Astroscleridae polyhedra, some ascidian spicules, siliceous sponge spicules, and pteropods.	1.6% of total. Similar to Grade No. 5, but with increased proportion of small whole organisms, also many plant fibers.	1.1% of total. Fine calcareous particles and some ovoids that are larger than the average and are probably sponge or ascidian spicules, also much plant fiber material.
9.8% of total. Composition similar to Grade No. 2, but with small foraminifera, pteropods, ostracods, calcareous sponge spicules.	14.8% of total. Somewhat increased proportion of small whole organisms, foraminifera and ostracods more abundant than in sands near the beach, some ascidian spicules, very small fraction of 1% inorganic.	1.5% of total. Composition similar to Grade No. 4, but more sponge and ascidian spicules. Small fraction of 1% inorganic, including one tourmaline crystal, some volcanic glass, feldspar, and olivine.	0.9% of total. Composition similar to Grade No. 5, plus siliceous sponge spicules and Astroscleridae polyhedra. Some cellulose plant fibers.	1.6% of total. Very fine calcareous particles and aggregates, some cellulose plant fibers.
8.3% of total. Composition similar to Grade No. 2, also Dentalium, Miliolidae, sponge spicules. Small fraction of 1% inorganic (olivine and basalt).	9.8% of total. Composition similar to Grade No. 3, with increased proportion of foraminifera, ostracods, and pteropods.	1.0% of total. Composition similar to Grade No. 4, with addition of many Astroscleridae polyhedra, also some ascidian spicules.	0.9% of total. Composition similar to Grade No. 5, many calcareous and siliceous sponge spicules. Very small fraction of 1% inorganic.	1.8% of total. Very fine calcareous particles and aggregates, much cellulose plant fiber material.
4.5% of total. Composition similar to Grade No. 2, with perhaps greater proportion of coral, also few alcyonarian spicules, Miliolidae, ostracods.	8.3% of total. Composition similar to Grade No. 3, with addition of some calcareous sponge spicules and increase in small foraminifera. Small fraction of 1% inorganic.	0.8% of total. Composition similar to Grade No. 4, with addition of some Astrocleridae polyhedra and ascidian spicules.	0.6% of total. Composition similar to Grade No. 5, with many calcareous and siliceous sponge spicules, no diatoms, some cellulose plant fibers.	1.6% of total. Very fine calcareous particles and aggregates, with some cellulose plant fibers.

TABLE 10—*Continued.*

Number and location.	Physical character and classification.	Summary composition, all grades.	Grade No. 1, fine gravel, 2.0 mm. to 1.0 mm.	Grade No. 2, coarse sand, 1.0 mm. to .5 mm.
1917 (0). Inner end of harbor off village, depth 12 feet.	A dark brownish-gray, very fine sand or silt, rather uniform size, no rounding of grains. Largely inorganic.	Largely an inorganic sand with several per cent of plant fiber material. Algae, mollusks, and foraminifera important calcareous constituents.	1.1% of total. Aggregates of clay and silt grades.	3.2% of total. Aggregates 90%, plant fibers 8%, Halimeda 1%, misc. 1%, including mollusks, foraminifera, and basalt.
1917 (1). Middle end of harbor, off Blacklock's wharf, depth 30 feet.	A brownish-gray silt of rather uniform size, more than 50% inorganic. Plastic and coherent when dry.	About half the composition inorganic, corals most important calcareous organism, algae and mollusks abundant.	0.0% of total.	0.0% of total.
1917 (2). Bottom of harbor off mooring buoy B, depth 138 feet.	A yellowish-gray silt of rather uniform size, largely organic, brown residue from HCl treatment of rock material.	.....	0.0% of total.	0.0% of total.
1917 (3). Bottom from middle of harbor off Goat Island, depth 164 feet.	A light gray silt, almost entirely organic, non-plastic, no appreciable rounding of grains.	Of heterogeneous composition with mollusk, Halimeda, and coral important constituents.	0.3% of total. Fine aggregates of clay and silt grades 50%, mollusks 30%, crustacea 15%, echinoids 5%.	1.7% of total. Composition similar to Grade No. 1 with few foraminifera.
1917 (4). Bottom from middle of harbor, just east of Whale Rock, depth 213 feet.	A light gray, very fine sand, with considerable range of sizes, almost entirely organic, non-plastic.	Composition similar to 1917 (3).	0.1% of total. Mollusks 30%, crustacea 27%, pteropods 7%, foraminifera 8%, echinoid plates 14%, aggregates 14%.	0.8% of total. Aggregates of clay and silt grade 52%, foraminifera 6%, mollusks 14%, Corallinaceae 7%, bryozoa 3%, Halimeda 2%, echinoids 2%, crustacea 6%, sponge spicules 2%, coral 4%, magnetite 1%, olivine 1%.
1917 (5). Silt from live car containing corals in the silted region 150 feet from mouth of large brook at inner end of harbor.	A mottled dark-brown fine sand, with considerable range in size, largely inorganic, non-plastic.	Largely inorganic with very small percentage of mollusks, Halimeda, coral, and foraminifera.	0.0% of total.	1.4% of total. Aggregates of silt and clay size 50%, igneous rock 25%, volcanic glass 13%, plant fiber 5%, feldspar 1%, olivine 1%, mollusks, crustacea, foraminifera, Halimeda 5%.

"Aggregates" is used to indicate aggregates of finer grades, largely silt and clay.

TABLE 10—*Continued.*

Grade No. 3, medium sand, 0.5 to 0.25 mm.	Grade No. 4, fine sand, 0.25 to 0.1 mm.	Grade No. 5, very fine sand, 0.1 to 0.05 mm.	Grade No. 6, silt, 0.05 to 0.005 mm.	Grade No. 7, clay, 0.005 to 0.000 mm.
1.0% of total. Aggregates 80%, plant fibers 13%, basic rock 3%, calcareous organisms 4%, including Halimeda, mollusks, ostracod, Corallinaceae, crustacea.	8.4% of total. Aggregates 65%, plant fibers 15%, igneous rock 10%, mineral fragments 2%, including olivine, feldspar, magnetite. Halimeda 4%, ostracods 2%, misc. 2%, including mollusks, crustacea, foraminifera.	41.6% of total. Volcanic glass 40%, igneous rock 35%, magnetite 6%, olivine, feldspar, pyroxene 6%, siliceous spicules 3%, calcareous organisms 10% including same as in Grade No. 4, but less ostracods and more foraminifera.	40.1% of total. Mineral and rock fragments 85%, magnetite 5%, siliceous spicules 2%, calcareous material 8%.	5.0% of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material. About 5% plant fibers.
0.1% of total. Mollusks 40%, crustacea 20%, aggregates 25%, plant fiber 10%, Corallinaceae 5%.	12.6% of total. Aggregates 67%, coral 24%, Halimeda 3%, mollusk 3%, foraminifera 1%, volcanic glass 1%, feldspar 1%. Rare alcyonaria and sponge spicules, echinoids, pteropods, plant fibers, olivine.	24.0% of total. Aggregates 70%, igneous rocks 13%, olivine, feldspar, magnetite 5%, coral 6%, Astroscleridae polyhedra 1%, misc. 5%, including Halimeda, foraminifera, mollusks, crustacea, and calcareous sponge spicules.	54.2% of total. Composition similar to Grade No. 5, but with about 15% calcareous material.	9.6% of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material.
0.0% of total.	4.6% of total. Aggregates 45%, igneous rock 10%, feldspar, magnetite, olivine, 2%, Halimeda 15%, mollusks 11%, crustacea 5%, coral 5%, foraminifera 3%, pteropods 3%, ostracods 2%, echinoids 2%, alcyonarian, holothurian, and sponge spicules 1%.	22.6% of total. Aggregates 40%, rock 8%, mineral fragments 2%, Astroscleridae polyhedra 13%, Halimeda 9%, pteropods 5%, Corallinaceae 5%, coral 5%, mollusks 4%, foraminifera 3%, ostracods 2%, echinoids 2%, sponge spicules 1%, ascidian spicules 1%, rare coprolitic pellets, bryozoa.	59.4% of total. Inorganic about 20%, as in Grade No. 4. Organic composition similar to grade No. 5, but with increase in spicules and smaller whole forms.	13.8% of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material.
0.8% of total. Composition similar to Grade No. 2, with mollusks chiefly pteropod, few Halimeda fragments.	3.4% of total. Composition similar to Grade No. 3, but with slight decrease in aggregates and crustacea, and increase in mollusks largely pteropods, occasional alcyonaria and sponge spicules, and inorganic fragments.	28.7% of total. Mollusk 22%, coral 14%, Astroscleridae polyhedra 8%, Halimeda 11%, foraminifera 10%, Corallinaceae 6%, sponge spicules 3%, bryozoa 2%, echinoid 2%, ascidian 2%, siliceous spicules 2%, inorganic 10%, including volcanic glass, cinder, olivine, basalt, feldspar.	60.2% of total. Composition similar to Grade No. 5, with increase in proportion of spicules.	4.8% of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material.
0.8% of total. Composition similar to Grade No. 2.	13.8% of total. Mollusk 20%, Corallinaceae 15%, foraminifera 12%, aggregates 11%, coral 10%, Halimeda 8%, bryozoa 5%, crustacea 5%, pteropods 5%, ostracod 2%, alcyonarian spicules 2%, echinoids 2%, calcareous sponge spicules 1%, rock and minerals 2%.	46.4% of total. Composition similar to Grade No. 4, but with addition of about 10% Astroscleridae and ascidian spicules, many siliceous monaxons, and few siliceous ovoid spicules.	32.6% of total. Composition similar to Grade No. 5, with increase in proportion of spicules and other small bodies. About 10% inorganic material.	5.4% of total. Very fine calcareous and inorganic particles and aggregates of these with colloidal material.
1.8% of total. Aggregates 15%, igneous rock 70%, volcanic glass 10%, feldspar 1%, olivine 1%, Ostracods, foraminifera, mollusks, Halimeda, crustacea 3%.	43.9% of total. Acid rock 32%, volcanic glass 20%, basic rock 15%, magnetite 15%, olivine 6%, ilmenite 5%, augite 1%, feldspar 1%, misc. 1%, including mica, hornblende chlorite, tourmaline, calcareous organisms 4%, including foraminifera, mollusks, Halimeda, and crustacea.	40.6% of total. Magnetite 35%, remainder 65%, similar in composition to Grade No. 4 but with larger proportion of mineral grains as compared to rock grains.	10.2% of total. Composition similar to Grade No. 4, few siliceous sponge spicules and plant fibers, only few p. ct. of calcareous material.	2.8% of total. Fine particles and aggregates. Largely inorganic. Much cellulose plant fiber.

PROPORTIONS OF DETRITAL ORGANIC CALCAREOUS CONSTITUENTS AND THEIR CHEMICAL ALTERATION IN A REEF SAND FROM THE BAHAMAS.

By Marcus I. Goldman.

With one text-figure.

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PROPORTIONS OF DETRITAL ORGANIC CALCAREOUS CONSTITUENTS AND THEIR CHEMICAL ALTERATION IN A REEF SAND FROM THE BAHAMAS.[1]

By Marcus I. Goldman.

RELATION TO PREVIOUS INVESTIGATIONS.

This investigation is a direct continuation (interrupted by the war) of the similar examination of samples from Murray Island, Australia, previously reported on.[2] Most of the general discussion in that paper is applicable to the present study. Like the Murray Island samples, this one consists, in the portions coarse enough for quantitative study, mainly of fragments of the calcareous skeletons of invertebrates and of calcareous algæ. The two principal defects noted in the study of the Murray Island samples have been corrected in this investigation, namely, the estimated relative volume units of the constituents instead of the mere number of grains was recorded,[3] and *Halimeda* was differentiated from the coralline algæ.[4] Estimating and recording relative volumes has led to results which, on the whole, check much better with the original weights (see table 3, p. 47, column 7). The Geophysical Laboratory of the Carnegie Institution of Washington kindly granted the use of its Keller assay balance for weighing the lots of different constituents. This balance has a sensitivity of about 0.04 mg. per division. In the fine gravel most of the lots weighed ranged from less than 0.5 mg. to more than 6.0 mg., in the coarse sand less than 0.3 mg. to more than 2.0 mg. In portions finer than the coarse sand no weighings were made. Unfortunately the weighings of the portions taken for study were not made on so delicate a balance, and hence have not the same accuracy.

For the medium, fine, and very fine sand the weight ratios were generalized, as shown in table 2, page 45, from those obtained for the fine gravel and coarse sand.

ORIGIN AND FIELD RELATIONS OF THE SAMPLE.

The sample, on the study of which this report is based, is a composite of equal parts of the four samples numbered 190 to 193 from

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] M. I. Goldman. Composition of two Murray Island bottom samples according to source of material. Carnegie Inst. Wash. Pub. No. 213, pp. 249-262, 1918.

[3] Cf. Carnegie Institution of Wash. Pub. No. 213, p. 253, last paragraph, and p. 47 of this paper.

[4] *Ibid.*, p. 251, first paragraph.

Andros Island, Bahamas. Andros Island lies on the east edge of the main platform of the Great Bahama Bank facing, to the east, the deep water of the Tongue of the Ocean, a depression which penetrates into the bank. The samples are discussed and the exact locality from which they were gathered is given in Publication No. 213 of the Carnegie Institution of Washington, referred to above, from which the map reproduced herewith, figure 1, is taken. The general geology and the various sedimentary facies of the region are discussed by Vaughan and his associates in that and in several other papers.[1]

The area from which the sample comes lies just behind the barrier reef of Cocoa-nut Point, which is almost the northeast end of Andros Island. Of the general area behind this barrier reef, Vaughan, describing especially a part farther south around the mouth of South Bight, says: "The present barrier reef is growing on the edge of a platform which is submerged to a depth of about 2 fathoms."[2] "There is, on the seaward face of the reefs, a rapid drop to depths between 4 and 10 fathoms."[3]

DISCUSSION OF THE METHOD OF ANALYSIS.

GENERAL CONSIDERATIONS.

The constituents differentiated quantitatively in this sample were the following:

- Madreporaria.
- Coralline algæ.
- Halimeda.
- Foraminifera—subdivided when possible into:
  - Orbiculina.
  - Orbitolites.
  - Textularia.
  - Polytrema.
  - Miliolid[4]
- Mollusks.
- Bryozoa.
- Crustacea (undifferentiated).
- Malacostraca.
- Balanids.
- Alcyonaria.
- Echinoderms.
- Worm tubes.
- Calcareous sponge spicules.
- Limestone.
- Gypsum.

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[1] Year Book Carnegie Inst. Wash. No. 11 for 1912 [1913].
G. Harold Drew. Report of investigations on marine bacteria carried on at Andros Island . . . , in May 1912, pp. 136-144.
T. W. Vaughan. Studies of the geology and of the madreporaria of the Bahamas and of southern Florida, pp. 153-156.
Same, No. 12 for 1913 [1914].
T. W. Vaughan. Investigations of the geology and geologic processes of the reef tracts and adjacent areas in the Bahamas and Florida, pp. 183-184.
Same, No. 13 for 1914 [1915].
T. W. Vaughan. Geological investigations in the Bahamas . . . , pp. 227-232.
T. W. Vaughan. Remarks on the geology of the Bahama Islands, and on the formation of the Floridian and Bahaman oölites. Jour. Wash. Acad. Sci., *3*, No. 10, May 19, 1913.
Carnegie Inst. Wash. Pub. No. 182, 1914.
G. H. Drew. On the precipitation of calcium carbonate in the sea by marine bacteria, and on the action of denitrifying bacteria in tropical and temperate seas, pp. 9-45, especially pp. 31-44.
T. W. Vaughan. Preliminary remarks on the geology of the Bahamas, with special reference to the origin of the Bahaman and Floridian oölites, pp. 49-54.

[2] Carnegie Inst. Wash. Year Book No. 13, p. 230, last paragraph.

[3] Carnegie Inst. Wash. Year Book No. 11, p. 155.

[4] Some fragments of miliolids could be differentiated under the microscope by the imperforate condition of their shells.

The organic forms are for the most part the same as those differentiated in the Murray Island sample, but in that sample no bryozoa, alcyonaria, or calcareous sponge spicules were identified, and there were different species of foraminifera. The fragments identified as limestone were presumably derived from the adjacent shore. They had a grain much coarser than other known constituents, in these respects resembling known fragments of limestone, but no oölitic or other definite recognizable structure, hence their identification was not very satisfactory.

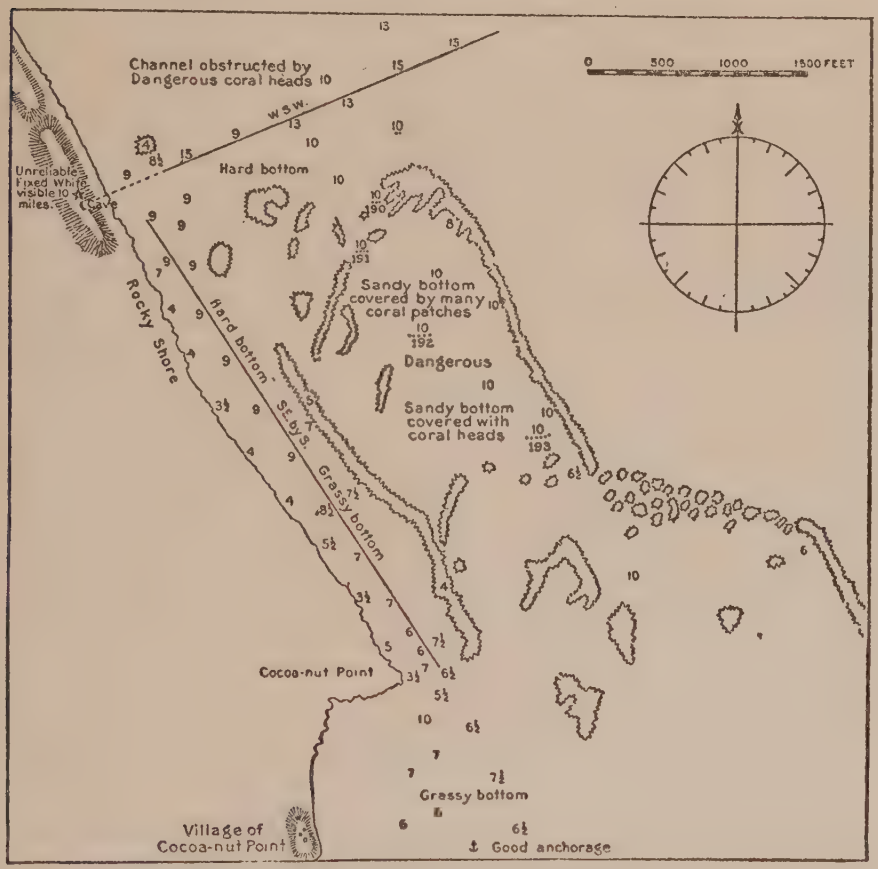

FIG. 1—Map of Bethel Entrance, Andros Island, Bahamas.
Position of light, Lat. 25° 8′ N., Long. 78° 0′ 30″ W.
From a plane-table survey by Alfred G. Mayer, May 1914.
Depths in feet.

So far as one's memory may be trusted in such a matter, especially where there was a long interruption to the work, the identification of grains was even more difficult than in the Murray Island sample. The greatest difficulty was connected with the identification of coralline algæ. From certain grains examined, in which the cell struc-

ture was in part visible, it seemed quite certain that this form often shows no recognizable character other than a relatively coarse, dense, dark granularity, and undiagnostic grains of this kind seemed much more common in this sample than in those from Murray Island. This granularity is characteristic of the skeleton of coralline algæ, but in good fresh material usually surrounds more or less discernible cells of the organism. It appears as though, lying on the bottom, the grains undergo some change, addition, or rearrangement of material which obliterates the cell structure. The peculiar granular structure itself and a possible porosity suggested by the relative lightness compared with madreporarian fragments (see table 2, p. 46) may be responsible for this ease of alteration, but dark granular patches, more or less like this, are not uncommon in many other forms. Fragments of *Halimeda*, especially if they are too small to show the characteristic reticulate structure, tend to resemble these undiagnostic fragments of coralline algæ; so do worm tubes and other constituents. Besides, there is always the possibility that, in the absence of more diagnostic characters, there may be other unknown forms which are characterized by a similar granularity. Both these considerations bear especially on the very fine sand (see table 4, p. 48). The proportion of this sample identified as *Halimeda* is much below that in the coarser portions, while the proportion of coralline algæ is abnormally large, in spite of the fact that the directly determined ratio of magnesia to lime is smaller in this portion than in the coarser ones. Further, in support of the second point—the possible existence of unknown forms with a similar undiagnostic structure—at least five, or nearly 20 per cent, of the grains identified as coralline algæ in that portion seemed more smooth and rounded than the ordinary grain, rather suggesting some definite growth element, whether organic or inorganic. They showed no internal radial, concentric, or nuclear structure, so that there was no reason for regarding them as oölites, yet some doubt as to their identification remains.

It will not be worth while to go more into details about other difficulties in identification and differentiation. Suffice it to say that they are numerous and not definite enough to permit much generalization about them. I repeat my conviction that if studies of this kind are to be continued they should be founded on a preliminary study of known material, as nearly as possible of all the skeleton-secreting forms contributing to the sands to be studied; and that still more fundamental, though requiring much more time, is an analytic study of skeletons of different groups and forms with a view to learning the method of their formation and the principles of their structure, so that unknown fragments may be identified on this basis rather than from mere general impressions of vague and partial resemblances to

known materials. It must be recognized, however, that even with this knowledge there will be difficulties in recognizing fragments, due not only to probably fundamental resemblances between the skeletons of different organisms, but especially to the changes which many fragments have probably undergone while lying on the bottom.

It occurred to me that it might be possible to make much better identifications by working with thin sections of the grains, instead of with the fragments obtained by crushing them. In general, it is quite possible to obtain thin sections, though the risk of losing fragments in trying to make thin sections is greater than in trying to crush them. In the medium sand (No. 3) 15 grains were therefore turned over to the rock-cutting laboratory of the U. S. Geological Survey to be thin-sectioned; 5 of these were lost. To my great surprise, the thin sections of the remaining 10 were so lacking in diagnostic characters that identification was impossible.

Staining was also tried out with a view to differentiating the more magnesian grains from those with little or no magnesia. The method of Lemberg with logwood and $AlCl_3$, as described by E. Steidtmann,[1] was tried but did not seem delicate enough, and was objectionable on account of the instability of the solution. The silver nitrate and pyrogallic acid method of Lemberg, as described and recommended by L. Cayeux,[2] appeared to give more differentiation if the solutions were sufficiently diluted and the grains exposed very briefly to the silver nitrate. But other factors than original chemical composition, porosity for instance, seem to affect the result. Besides, the blackish coating formed conceals the internal and surface texture, which are very valuable aids in identification of uncrushed grains. The darkness of the coating also makes it harder to recognize details of external form. On the whole, therefore, more was lost than gained by the use of the stain.

In view of the uncertainty of many of the identifications, it seemed that it might be worth while to distinguish, in the final results, between those that were definitely identified and those about which there was uncertainty; but when this was attempted it was found that the gradation from certain to uncertain was so gradual and complete that it was impossible to draw a definite line of division. In spite of all these difficulties, however, I do not want to give the impression that the count has not a rough quantitative value, at least in the four coarsest sizes. The identifications of foraminifera and echinoderms are generally very reliable and a great many fragments of *Halimeda* can be identified with certainty from their external appearance; of mollusks the identifications are also very good; of

[1] Origin of dolomite as disclosed by stains and other methods. Bull. Geol. Soc. Am. *28*, p. 435, 1917.

[2] Introduction à l'étude pétrographique des roches sédimentaires, p. 183, 1916.

madreporaria perhaps a little less. Bryozoa and crustacea caused me much uncertainty, probably largely because they are not encountered often enough to become familiar. In crushed fragments under the microscope bryozoa tend especially to resemble madreporaria. Fragments of worm tubes are generally quite undiagnostic, unless they represent a complete segment of a tube. Regarding coralline algæ, which have been discussed above, it may be said in addition that certain rather rare rod-like fragments are easily identified by their internal as well as external character.

METHOD OF PROCEDURE.

The method of conducting the count may be briefly summarized as follows:

A number of grains bearing some relation to the size of the portion was selected from each size portion, as much at random as possible. In the two coarsest portions these lots were weighed. A more or less spherical grain was then selected from each portion as a standard to be used in estimating the relative volumes of the other grains studied in that portion.[1] The grains were then placed for study on a plate of glass with a dark background for the unstained grains or a white one for the stained grains, and taken one at a time at random. After their relative volume had been estimated, grains such as many foraminifera, halimeda, etc., which could be readily identified by their external form, were put aside for weighing, in vials assigned to the form to which the grain belonged. In the four coarsest sizes, so far as possible, part of grains not so identified was cut off with a sharp knife. In doing this it was found best to place the grain on a thin layer of some plastic substance to prevent snapping it away. The manufactured modeling-clay "plasticene" was found convenient, as it is composed largely of grease, so that the grain could readily be cleaned of any adhering "plasticene" by putting it in ether. The volume of each portion of the grain was then estimated. The smaller fragment cut off from the grain was either crushed and then covered with a drop of a rather thin solution of Canada balsam in xylol and a cover glass, or preferably was crushed after being covered. The remainder of the grain, after the crushed portion had been identified, was put aside, like the entire grains, for subsequent weighing. The following form of notes was used:

[1] The suggestion made in the Murray Island report, cited above (see p. 253 of that report), that a lead shot be used as a standard of volume is inapplicable to any but the coarsest size, since No. 12 shot (American system), apparently the smallest made, measures between about 1.1 and 1.4 mm. diam. (cf. table 1, p. 46).

No. of grain.	Form.	Estimated volume units.		
		Destroyed.	Kept.	Total.

For purposes of identification each grain was given a current number. Under the column "Form," in addition to the identification, any distinctive peculiarities of grains were noted and sketched. This was found very useful when there was difficulty in identifying a grain from the crushed portion, especially if later evidence from other grains revealed the identity of the grain. In the case of one puzzling fragment that turned out to be crustacean an enlarged photograph was even made.

ACCURACY OF VOLUME ESTIMATES.

There is no doubt that the estimation of volume units was not very accurate. This was discovered when all the segregated grains of a certain constituent were taken out at one time and compared with each other, with the original volume estimate and with the volume standard. Apparently estimates made at widely separated intervals are likely to vary quite widely. However, I know no reason why these errors should not tend to compensate each other.

RELATION OF ACTUAL TO RECORDED DISTRIBUTION OF FORMS.

It is also obvious that the count, even if it were possible to make positive identifications of all grains, can not represent very accurately the proportion of the less abundant constituents and that, moreover, some of the rarer ones have probably not been included in the portion taken for examination. The limits of accuracy of the method did not, however, seem to justify any more extensive count. The attempt was made, throughout, to make all selections as random as possible, so that any losses or replacements of lost grains would not appreciably affect the degree of accuracy sought.

RESULTS OF ANALYSIS.

The results of the study are presented in the following tables:

TABLE 1.—*Mechanical analysis of sample.*[1]

Size.		Diameter of grains (mm.).	Weight.[2]	Weight per cent.
No.	Name.			
1	Fine gravel	2 to 1	15.5	4.0
2	Coarse sand	1 to 0.5	60.0	15.0
3	Medium sand	0.5 to 0.25	82.6	21.0
4	Fine sand	0.25 to 0.1	226.4	56.5
5	Very fine sand	0.1 to 0.05	9.8	2.0
6	Silt	0.05 to 0.005	1.8	0.5
7	Clay	less than 0.005	5.1	1.0
	Total		401.2	100.0

[1] By the Bureau of Soils, U. S. Dept. of Agric.

[2] Combined from weight percentages of samples 190, 191, 192, and 193 as given in Pub. No. 213, Carnegie Inst. Wash., p. 263, 1918.

TABLE 2.—*Unit weights.*

Form.	Weight ratios.		
	In fine gravel.	In coarse sand.	Take for finer sizes.
Madreporaria	100.00	100.00	100.00
Coralline algæ	[1](86.7)	[1](87.8)	90.00
Halimeda	64.80	51.60	60.00
Foraminifera (undifferentiated)	48.80	64.40	[2]60 to 80
Orbiculina	45.50	51.50	[2]60 to 80
Orbitolites	.....	56.55	[2]60 to 80
Textularia	32.60	62.50	[2]60 to 80
Polytrema	38.75	(38.80)	40
Miliolids	.....	.....	[2]70 to 80
Mollusks	56.80	42.10	50 to 90
Bryozoa	(53.80)	(41.90)	60
Malacostraca	(89.80)	.....	90
Balanids	.....	.....	90
Alcyonaria	.....	53.70	55
Calcareous sponge spicules	.....	25.80	40
Worm tubes	.....	.....	[2]40 to 80
Echinoderms	.....	.....	70
Limestone	.....	(83.80)	80
Gypsum	.....	(94.30)	95

Unbracketed quantities in first two columns are the results of actual weighings, those in parentheses are estimated or adjusted.

[1] Corrected unit weights finally used have been used to derive this ratio.

[2] Higher values for fragments not including chambers, hence also in finer-sized portions.

TABLE 3.

Form.	No. of grains.	P. ct. of total number.	Total vol. units.	P. ct. of total volume.	Average vol. units per grain.	First unit wt. in mg.	First total calculated wt. in mg.	Adjusted unit wt.[1] in mg.	Total recalc. wt., in mg.	Percentage in wt.
Fine gravel (No. 1).										
Madreporaria	5	10.2	5.55	13.7	1.11	1.670	9.26	.....	9.26	19.1
Coralline algæ	13	25.5	14.55	36.0	1.12	1.361	19.81	1.448	21.07	43.4
Halimeda	9	17.6	7.15	17.7	0.79	1.082	7.74	.....	7.74	15.9
Foraminifera (undifferentiated)	9	17.6	3.85	9.5	0.43	0.815	3.14	.....	3.14	6.5
Orbiculina	7	13.7	4.90	12.1	0.70	0.760	3.72	.....	3.72	7.7
Polytrema	1	1.9	0.45	1.1	0.45	0.6475	0.29	.....	0.29	0.6
Textularia	1	1.9	1.20	3.0	1.20	0.545	0.65	.....	0.65	1.3
Mollusks	4	7.8	1.25	3.1	0.31	0.950	1.19	.....	1.19	2.4
Bryozoa	1	1.9	1.15	2.9	1.15	0.900	1.04	.....	1.04	2.1
Crustacea	1	1.9	0.35	0.9	0.35	1.5	0.50	.....	0.50	1.0
	51	.....	40.40	100.0	.....	.....	47.34	.....	48.60	100.0
Original weight of lot	.....	.....	.....	.....	.....	.....	48.60	.....	.....	.....
Difference	.....	.....	.....	.....	.....	.....	[2]1.26			
Coarse sand (No. 2).										
Madreporaria	17	16.5	9.95	15.3	0.57	0.477	4.75	.....	4.75	23.0
Coralline algæ	18	16.5	12.15	18.7	0.675	0.446	5.42	0.419	5.09	24.6
Halimeda	30	29.0	18.40	28.3	0.94	0.246	4.53	.....	4.53	21.9
Foraminifera (undifferentiated)	16	16.0	9.80	15.1	0.61	0.3075	3.01	.....	3.01	14.5
Orbiculina	3	3.0	2.75	4.2	0.92	0.246	0.68	.....	0.68	3.3
Orbitolites	3	3.0	1.80	2.8	0.60	0.267	0.48	.....	0.48	2.3
Textularia	1	1.0	1.10	1.7	1.10	0.298	0.33	.....	0.33	1.6
Polytrema	2	2.0	0.45	0.7	0.27	0.185	0.08	.....	0.08	0.4
Mollusks	7	7.0	6.00	9.2	0.86	0.201	1.21	.....	1.21	5.8
Bryozoa	1	1.0	0.40	0.6	0.40	0.2	0.08	.....	0.08	0.4
Alcyonaria	1	1.0	1.25	1.9	1.25	0.256	0.32	.....	0.32	1.5
Calcareous sponge spicules	1	1.0	0.75	1.2	0.75	0.123	0.09	.....	0.09	0.4
Limestone	1	1.0	0.05	0.1	0.05	0.4	0.002	.....	0.002	0.1
Gypsum	1	1.0	0.10	0.2	0.10	0.45	0.05	.....	0.05	0.2
	102	100.0	64.95	100.0	0.637	.....	21.03	.....	20.70	100.0
Compound grains	6	.....	.....	.....	.....	.....	.....	.....	.....	.....
Number taken	96	.....	.....	.....	.....	.....	.....	.....	.....	.....
Original weight of lot	.....	.....	.....	.....	.....	.....	20.7	.....	.....	.....
Difference	.....	.....	.....	.....	.....	.....	[3]0.33	.....	.....	.....

[1] In adjusting the weights calculated from observed or assumed weights, to make the total calculated weight conform to the original determined weight of the lot taken for determination, no attempt was made at a mathematical procedure, since there seemed no basis for one. As the first calculated weight in the fine gravel was low, it was entirely adjusted by taking a unit weight for the coralline algæ nearer the average of the determined unit weights of this constituent in the fine gravel and the coarse sand and the same change, but with the opposite sign, was made in the coarse sand.

[2] 2.59 per cent of original weight.

[3] 1.64 per cent of original weight.

TABLE 4.

Form.	No. of grains.	P. ct. of total number.	Total vol. units.	P. ct. of total volume.	Average vol. units per grain.	Assumed unit wt. ratio.	Weight ratios.	Weight percentages for portion.
Medium sand (No. 3).								
Madreporaria	19	23.2	9.65	21.9	0.508	100	965	26.7
Coralline algæ	21	25.6	11.40	25.9	0.543	90	1,026	28.4
Halimeda	20	24.4	9.70	22.0	0.485	60	582	16.1
Foraminifera (undifferentiated)	1	1.2	1.00	2.3	1.00	70	70	1.9
Miliolids	2	2.5	0.70	1.6	0.35	70	49	1.3
Mollusks	10	12.2	6.45	14.6	0.645	80	516	14.3
Alcyonaria	1	1.2	1.10	2.5	1.10	55	60	1.7
Crustacea (undifferentiated)	3	3.5	1.65	3.7	0.55	90	148	4.1
Balanids	1	1.2	0.60	1.4	0.60	90	54	1.5
Worm tubes	2	2.5	0.55	1.3	0.27	80	44	1.2
Limestone	2	2.5	1.25	2.8	0.62	80	100	2.8
	82	100.0	44.05	100.00	.....	.....	3,614	100.00
Compound grains	3							
Number taken	79							
Fine sand (No. 4).								
Madreporaria	29	29.9	28.75	24.4	0.992	100	2,875	29.9
Coralline algæ	24	24.7	35.90	30.5	1.493	90	3,231	33.6
Halimeda	20	20.6	22.05	18.7	1.102	60	1,323	13.8
Foraminifera (undifferentiated)	4	4.1	5.70	4.8	1.425	75	427	4.4
Miliolids	2	2.1	0.80	0.7	0.400	80	64	0.6
Mollusks	2	2.1	1.80	1.5	0.900	90	162	1.7
Bryozoa	5	5.1	5.75	4.9	1.150	60	345	3.6
Alcyonaria	2	2.1	2.90	2.5	1.450	55	159	1.6
Worm tubes	3	3.1	4.10	3.5	1.367	70	287	3.0
Echinoderms	3	3.1	5.25	4.5	1.750	70	367	3.8
Limestone	3	3.1	4.80	4.0	1.600	80	384	4.0
	97	100.0	117.80	.....	.....	.....	9,624	100.0
Compound grains	1							
No. of grains identified	96							
Very fine sand (No. 5).								
Madreporaria	12	19.7	10.25	15.2	0.854	100	1,025	17.9
Coralline algæ	26	42.6	30.80	45.8	1.185	90	2,772	48.2
Halimeda	2	3.3	2.85	4.2	1.425	60	171	3.0
Foraminifera	7	11.5	7.65	11.4	1.093	80	612	10.6
Mollusks	5	8.2	4.30	6.4	0.860	90	387	6.7
Bryozoa	1	1.6	1.00	1.5	1.000	60	60	1.0
Alcyonaria	3	4.9	4.00	6.0	1.333	55	220	3.8
Echinoderms	2	3.3	1.55	2.3	0.775	70	108	1.9
Crustacea	2	3.3	4.00	6.0	2.000	90	360	6.3
Calcareous sponge spicules	1	1.6	0.80	1.2	0.800	40	32	0.6
	61	100.0	67.20	100.0	.....	.....	5,747	100.0
Not identified	1	.....	0.40					
	62	.....	67.60					
Compound grains	3							
No. of grains taken	59							

TABLE 5.—*Assumed compositions.*

Form.	$CaCO_3$.	$MgCO_3$.	$CaSO_4$.	$Ca_3P_2O_8$.
Madreporaria	99.50	0.50	.....	.....
Coralline algæ	78.80	20.00	1.20	.....
Halimeda	98.75	0.75	0.50	.....
Orbiculina	90.00	10.00	.....	.....
Orbitolites	89.40	10.60	.....	.....
Textularia	(90.00)	(10.00)	.....	.....
Polytrema	88.75	11.25	.....	.....
Miliolids	90.50	9.50	.....	.....
Foraminifera (undifferentiated)	90.00	10.00	.....	.....
Mollusks	99.75	0.25	.....	.....
Bryozoa	93.50	5.00	1.50	.....
Echinoderms	88.25	10.50	1.25	.....
Malacostraca	70.00	12.50	1.50	16.00
Balanids	98.50	1.50	.....	.....
Crustacea (undifferentiated)	80.00	10.00	1.00	9.00
Limestone [1]	99.75	.....	0.25	.....
Sponge	92.00	7.00	1.00	.....
Alcyonaria	81.00	13.00	3.00	3.00
Worm tubes	94.00	5.00	1.00	.....

[1] Carnegie Institution Wash. Pub. No. 213, pp. 269–270, 1918.

TABLE 6.—*Chemical compositions.*

	Calculated percentage by weight.	Calculated composition.				SiO_2 $(FeAl)_2O_3$ Insol.
		$CaCO_3$	$MgCO_3$	$CaSO_4$	$Ca_3P_2O_8$	
Fine gravel.						
Madreporaria	19.1	19.0	0.1	.....	.....	.....
Coralline algæ	43.4	34.2	8.7	0.5	.....	.....
Halimeda	15.9	15.7	0.1	0.1	.....	.....
Orbiculina	7.7	7.0	0.7	.....	.....	.....
Textularia	1.3	1.2	0.1	.....	.....	.....
Polytrema	0.6	0.5	0.1	.....	.....	.....
Foraminifera (undifferentiated)	6.5	5.8	0.7	.....	.....	.....
Mollusks	2.4	2.4	0.0	.....	.....	.....
Bryozoa	2.1	2.0	0.1	.....	.....	.....
Malacostraca	1.0	0.7	0.1	.....	0.2	.....
Total calculated	.....	88.5	10.7	0.6	0.2	.....
Total determined	.....	93.72	6.28	Tr.	0.00	Tr.
Coarse sand.						
Madreporaria	23.0	22.9	0.1	.....	.....	.....
Coralline algæ	24.6	19.4	4.9	0.3	.....	.....
Halimeda	21.9	21.6	0.2	0.1	.....	.....
Orbiculina	3.3	3.0	0.3	.....	.....	.....
Orbitolites	2.3	2.1	0.2	.....	.....	.....
Textularia	1.6	1.4	0.2	.....	.....	.....
Polytrema	0.4	0.4	.....	.....	.....	.....
Foraminifera (undifferentiated)	14.5	13.0	1.5	.....	.....	.....
Mollusks	5.8	5.8	.....	.....	.....	.....
Bryozoa	0.4	0.4	.....	.....	.....	.....
Alcyonaria	1.5	1.2	0.2	0.05	0.05	.....
Calcareous sponge spicules	0.4	0.4	.....	.....	.....	.....
Limestone	0.1	0.1	.....	.....	.....	.....
Gypsum	0.2	.....	.....	0.2	.....	.....
Total calculated	100.0	91.7	7.6	0.7	Tr.	.....
Total determined	.....	94.13	5.77	Tr.	0.00	0.1

TABLE 6.—*Chemical compositions*—Continued.

	Calculated percentage by weight.	Calculated composition.				SiO_2 $(FeAl)_2O_3$ Insol.
		$CaCO_3$	$MgCO_3$	$CaSO_4$	$Ca_3P_2O_8$	
Medium sand.						
Madreporaria	26.7	26.6	0.1	.....	.....	.....
Coralline algæ	28.4	22.4	5.7	0.3	.....	.....
Halimeda	16.1	15.9	0.1	0.1	.....	.....
Miliolids	1.3	1.2	0.1	.....	.....	.....
Foraminifera (undifferentiated)	1.9	1.7	0.2	.....	.....	.....
Mollusks	14.3	14.3	.....	.....	.....	.....
Alcyonaria	1.7	1.4	0.2	0.05	0.05	.....
Crustacea (undifferentiated)	4.1	3.3	0.4	0.1	0.3	.....
Balanids	1.5	1.5	.....	.....	.....	.....
Worm tubes	1.2	1.1	0.1	.....	.....	.....
Limestone	2.8	2.8	.....	.....	.....	.....
Total calculated	100.00	92.2	6.9	0.55	0.35	.....
Total determined	.....	94.13	5.77	Tr.	0.00	0.10
Fine sand.						
Madreporaria	29.9	29.8	0.1	.....	.....	.....
Coralline algæ	33.6	26.5	6.7	0.4	.....	.....
Halimeda	13.8	13.6	0.1	0.1	.....	.....
Miliolids	0.6	0.5	0.1	.....	.....	.....
Foraminifera (undifferentiated	4.4	4.0	0.4	.....	.....	.....
Mollusks	1.7	1.7	.....	.....	.....	.....
Bryozoa	3.6	3.4	0.2	.....	.....	.....
Alcyonaria	1.6	1.3	0.2	0.05	0.05	.....
Echinoderms	3.8	3.4	0.4	.....	.....	.....
Worm tubes	3.0	2.8	0.2	.....	.....	.....
Limestone	4.0	4.0	.....	.....	.....	.....
Total calculated	.....	91.0	8.4	0.55	Tr.	.....
Total determined	.....	94.50	5.37	Tr.	0.00	0.13
Very fine sand.						
Madreporaria	17.9	17.8	0.1	.....	.....	.....
Coralline algæ	48.2	38.0	9.6	0.6	.....	.....
Halimeda	3.0	3.0	.....	.....	.....	.....
Foraminifera	10.6	9.5	1.1	.....	.....	.....
Mollusks	6.7	6.7	.....	.....	.....	.....
Bryozoa	1.0	0.9	0.1	.....	.....	.....
Alcyonaria	3.8	3.1	0.5	0.1	0.1	.....
Echinoderms	1.9	1.7	0.2	.....	.....	.....
Crustacea	6.3	5.0	0.6	0.1	0.6	.....
Calcareous sponge spicules	0.6	0.6	.....	.....	.....	.....
Total calculated	.....	86.3	12.2	0.8	0.7	.....
Total determined [1]	.....	92.8	3.5	?	?	.....

[1] Sample too small, only CaO and MgO determined.

SILT.

The silt portion was of course too fine for a quantitative identification of grains according to source. Following are the notes of a qualitative examination:

Diatoms.
Radiolarian (only one could be found in the lot taken for examination).
Triaxial siliceous sponge spicules. Siliceous sponge spicules are common.
Smooth calcareous spicule = sponge?
Coccoliths and coccospheres.
Bryozoon fragments are probably common.
Heavy prisms (of mollusks?)
Pteropod fragment?
Large spheres of highly birefringent radiating fibers = salts evaporated from solution in drying the sample (see clay, below).
The portion was too small for a determination of more than calcium and magnesum.
The result recalculated as carbonate is: $CaCO_3$, 80.3 per cent; $MgCO_3$, trace.

The low proportion of total carbonates is probably partly accounted for by the presence of siliceous organisms such as diatoms, sponge spicules, and radiolaria, and by some clayey substance. I have no suggestion to account for the small proportion of $MgCO_3$, unless it is part of the general decrease in the proportion of $MgCO_3$, with decrease in size of particles, which is discussed below, page 57.

CLAY.

This portion consists of finely granular material in which no differentiations can be made. There were, in the sample as received, large plates of a birefringent mineral, but this was removed by boiling with water and decanting and filtering so that it is obviously some soluble salt separated on evaporation of the water in which the clay was collected.

Like the silt this portion was too small to permit determination of more than CaO and MgO. The result recalculated as carbonates is: $CaCO_3$, 24.9 per cent; $MgCO_3$, trace.

DISCUSSION OF RESULTS.

OBJECTS OF THE INVESTIGATION.

The objects of this study are two:

First, it is part of a general study of bottom samples to illustrate their variations in relation to source and to conditions of accumulation. These general phases have been presented in the papers cited above.[1] On p. 263 of publication No. 213 of the Carnegie Institution, Vaughan gives chemical and mechanical analyses and an enumeration, in general terms, of the constituents of this sample. To this last the present study adds only a more definite numerical statement. It is doubtful, however, whether at the present stage of the study of sediments, with so many fundamental problems to be solved, the time

[1] See footnote 1, p. 40.

consumed in a count as detailed as this would be justified merely by that result, in view of its imperfections when attained and the variability of the composition according to local variations in the biota and local currents. A comparison of the organisms contributing to this sample and to the Murray Island sample as brought together in table 9 (p. 54) shows the lower madreporarian and higher algal content of this sample, lower molluskan content, and the presence in it of bryozoa, alcyonaria,[1] and sponge spicules not noted at all in the Murray Island samples. Diatoms and radiolaria noted in the silt from the Bahamas were not recorded from the Murray Island samples. Several of these differences can probably be attributed to the greater depth (10 feet as against a few inches), from which the Bahamas sample was taken.

The other and more important object of this study is to contribute quantitative data to the problem of the origin of dolomite.[2] The general fact that certain organisms, especially the coralline algæ, contribute magnesia to limestones has long been recognized,[3] but the unsolved phase of the problem to which it seemed that this study might contribute concerns the effect on these calcareous and magnesian fragments of immersion in ocean water. That is, whether there is any relative increase of the magnesia content either by mere solution of calcium carbonate[4] or by deposition of magnesium carbonate, either in pores and cavities or taking the place of calcium carbonate.[5]

RELATIONS OF CALCIUM AND MAGNESIUM CARBONATES IN THE SAMPLES.

A comparison of the estimated weight percentages, estimated chemical compositions, and determined chemical compositions of this sample and the Murray Island samples as presented in the following tables (tables 7 to 11) brings out certain discrepancies which make it advisable to consider the probabilities of error in the results for each area. Thus, table 7 shows rather close agreement between all the directly determined chemical compositions. But while the calculated compositions for the Murray Island samples, as shown in table 7, agree very closely with those directly determined, table 8 shows that this is not at all the case for the Bahamas sample. Table 9, in which the essentially calcareous and the essentially

[1] Cf. T. W. Vaughan, Carnegie Inst. Wash. Pub. No. 213, p. 264, 1918.

[2] For a very full review of this problem, with abundant references to the literature, see F. W. Clarke. The data of geochemistry, 5th ed., Bull. U. S. Geol. Survey No. 770, pp. 565-580, 1924.

[3] The earliest instance referred to by Clarke, op. cit., is G. Forchhammer. Oversigt Danske Vidensk. Selsk. Forhandl., 1849, pp. 83-96; also Brit. Assoc. Rep., 1849, pt. 2, pp. 36-37. (Reference taken from Roy. Soc. London, Catalog of Scientific Papers.)

[4] Cf. A. G. Högbom. Neues Jahrb. f. Min., etc., 1894, *1*, Abhandlungen, p. 262-274.

[5] Cf. E. W. Skeats. Amer. Jour. Sci. 4th ser., *45*, pp. 185-200, 1918.

magnesian organisms are grouped, shows plainly enough why there is this difference in the calculated compositions between the two regions, but affords no explanation of the resemblance in the determined compositions. This discrepancy strongly suggests, though it does not prove, that the calculated results for one or the other region are not sufficiently accurate to show definitely relative changes in magnesia content.

TABLE 7.—*Chemical composition of entire samples.*

	Bahamas composite 190-193.	Murray Island.			
		Sample 27353a.		Sample 27337.	
	Determined.[1]	Calculated.	Determined.	Calculated.	Determined.
$CaCO_3$	94.59	94.3	93.6	93.7	93.85
$MgCO_3$	5.24	4.6	5.8	5.0	5.5
SiO_2	0.09	0.60	0.60	0.63	0.63
$(AlFe)_2O_3$	0.08				
$Ca_3P_2O_8$	0.00	Trace	.....	Trace	0.00
$CaSO_4$	Trace	0.2	Trace	0.3	Trace

[1] By Alfred A. Chambers, U. S. Geological Survey.

TABLE 8.—*Chemical composition of 4 coarsest portions combined.*

	Bahamas composite 190–193. Sands 1 to 4[1]		Murray Island. Sands 1 to 4, calculated.	
	Determined.[2]	Calculated.	Sample 27353a.	Sample 27337.
$CaCO_3$	94.4	91.5	95.1	94.6
$MgCO_3$	5.6	7.9	4.7	5.1
$CaSO_4$	Trace.	0.5	0.2	0.3
$Ca_3P_2O_8$	0.00	0.1	Trace.	Trace.
	100.00	100.0	100.0	100.0

[1] The calculations were made for sands 1 to 5 of the Bahamas sample as well as for sands 1 to 4, but the small percentage of the entire sample in sand No. 5 (2 per cent) had no appreciable effect on the results. As the count of No. 5 is probably much less reliable than the others, the calculations for sands 1 to 5 are therefore not presented here.

[2] Summation of determinations by J. G. Fairchild, U. S. Geol. Survey, on each of the four sands separately.

TABLE 9.—*Relation between percentage of calcareous and magnesian constituents in Bahamas and Murray Island samples.*

	Percentage composition by weight.		
	Bahamas composite sample 190–193, sands Nos. 1 to 4.	Murray Island sands Nos. 1 to 4.	
		Sample 27353a.	Sample 27337.
Calcareous:			
Madreporaria	24.4	50.6	37.2
Halimeda	17.0	[1]12.7	[1]20.5
Mollusks	6.1	11.3	16.3
Limestone	1.7		
	49.2	74.6	74.0
Magnesian:			
Coralline algæ	32.6	[1]12.7	[1]20.5
Foraminifera	11.6	11.2	4.2
Crustacea	1.7	1.4	0.9
Alcyonaria	1.2	.....	.....
Bryozoa	1.5	.....	.....
Echinoderms	1.0	.....	.....
Worm tube	1.1	0.1	0.4
Calcareous sponge	0.1		
	50.8	25.4	26.0

[1] As coralline algæ and *Halimeda* were not differentiated in the Murray Island sample, their chemical contribution to the sample was calculated by taking the mean of the chemical composition of the two forms. As this is equivalent to assuming that the two forms were present in equal amounts, the total perçentage of algæ present has in this table been equally divided between the two forms.

TABLE 10.—*Bahama composite sample 190–193.*

	Fine gravel (No. 1).	Coarse sand (No. 2).	Medium sand (No. 3).	Fine sand (No. 4).	Very fine sand.	Silt.	Clay.	Total of organism.	Weight (p. ct.) of organisms in sands 1 to 4.
Madreporaria	19.1	23.0	26.7	29.9	.....	.....	.....	97.7	24.4
Halimeda	15.9	21.9	16.1	13.8	.....	.....	.....	67.7	17.0
Mollusks	2.4	5.8	14.3	1.7	.....	.....	.....	24.2	6.1
Limestone	.....	0.1	2.8	4.0	.....	.....	.....	6.9	1.7
Total	37.4	50.8	59.9	49.4	.....	.....	.....	.....	.....
Coralline algæ	43.4	24.6	28.4	33.6	.....	.....	.....	130.0	32.6
Foraminifera	16.1	22.1	3.2	5.0	.....	.....	.....	46.4	11.6
Alcyonaria	.....	1.5	1.7	1.6	.....	.....	.....	4.8	1.2
Bryozoa	2.1	0.4	.....	3.6	.....	.....	.....	6.1	1.5
Crustacea	1.0	.....	5.6	.....	.....	.....	.....	6.6	1.7
Worm tube	.....	.....	1.2	3.0	.....	.....	.....	4.2	1.1
Echinoderms	.....	.....	.....	3.8	.....	.....	.....	3.8	1.0
Calcareous sponge	.....	0.4	.....	.....	.....	.....	.....	0.4	0.1
Total	62.6	49.0	40.1	50.6	.....	.....	.....	.....	.....
Determined composition[1].									
$CaCO_3$	93.72	94.13	94.13	94.50	92.8	80.3	24.9	.....	.....
$MgCO_3$	6.28	5.77	5.77	5.37	3.5	Tr.	Tr.	.....	.....
Calculated composition:									
$CaCO_3$	88.5	91.7	92.2	91.0	.....	.....	.....	.....	.....
$MgCO_3$	10.7	7.6	6.9	8.4	.....	.....	.....	.....	.....

[1] By J. G. Fairchild, U. S. Geological Survey.

TABLE 11.—*Weight ratios in Murray Island samples (from Pub. No. 213, pp. 255 and 257).*

	Algæ.		Madreporaria.		Mollusks.		Foraminifera.	
	27353a.	27337.	27353a.	27337.	27353a.	37337.	27353a.	27337.
Fine gravel	34.45	39.75	11.30	26.75	12.95	27.40	38.60	6.10
Coarse sand	34.30	50.90	52.95	35.25	9.85	8.90	2.90	3.65
Medium sand	10.75	31.05	83.50	50.65	2.50	12.65	3.25	4.50
Fine sand	22.15	42.10	54.55	35.20	19.85	16.30	.....	2.75
	101.65	164.10	202.30	148.85	45.15	65.25	44.75	17.00

In favor of the Murray Island results is the fact that the material was probably more easily identified and that the agreement between the calculated and determined composition is close, which one is inclined to think is not a coincidence. The close agreement in table 9 between percentage of calcareous and magnesian organisms in the two Murray Island samples would also suggest the correctness of the count in each if inspection did not show that it is due to a chance coincidence in the summation of very different proportions of constituents in the two samples.

On the other hand, the Murray Island samples suffer from the very great defect that the magnesian coralline algæ were not differentiated from the calcareous *Halimeda*. In calculating the chemical contribution of the algæ to the Murray Island samples the average of the compositions of the two forms was used, which is equivalent to assuming that half of the total algæ belonged to each form, and they have been so represented in table 9. But there is no basis for this assumption, and as the coralline algæ are by far the greatest contributors of magnesia to the samples, an assumption about them, as was pointed out in the report on the Murray Island samples, makes the entire calculated composition inconclusive. At the same time the remarkably close agreement between the calculated and directly determined results attained by assuming such relative proportions of coralline algæ and *Halimeda* as would make the magnesium carbonate content the same in the calculated and the determined compositions (see table 12) inclines one to believe that the calculated results may

TABLE 12.

Samples.		$CaCO_3$.	$MgCO_3$.	$CaSO_4$.
27353a	Observed	93.0	5.8	0.2
	Calculated revised	93.6	5.8	Trace
27337	Observed	93.15	5.5	0.3
	Calculated revised	93.85	5.5	Trace

[1] From Carnegie Inst. Wash. Pub. No. 213, p. 261, 1918.

be approximately correct. At the time of writing the report on the Murray Island samples I did not realize how remarkably close this agreement was. But consideration of the fact that the summation of directly determined compositions for the different size portions of the Bahamas sample differs from the directly determined composition for the entire sample, as shown herewith (table 13), by 1 per cent of the total sample, and a little more than 1 per cent of the constituent, for $CaCO_3$ and by about 0.15 per cent of the total sample, or about 3 per cent of the constituent, for $MgCO_3$, makes a maximum difference of 0.7 per cent of the total sample for $CaCO_3$, in the revised calculated composition of the Murray Island sample, seem well within the limit of unavoidable error.

TABLE 13.—*Directly determined chemical compositions of Bahamas samples.*

	$CaCO_3$.	$MgCO_3$.	$CaSO_4$.	$Ca_3P_2O_8$.	SiO_2.	$(Al, Fe)_2O_3$.	Insol.
Direct determination on total sample.....	94.59	5.24	Trace	0.00	0.09	0.08	.....
Summation of direct determination on size portions, reduced to 100 per cent.....	93.6	5.4	?	?	?	?	?

Another doubtful feature of the Murray Island count is brought out by a comparison of table 11 with table 10. Table 11 shows that the proportion of any one form in different size portions varies very irregularly in the Murray Island sample, while table 10 shows that in the Bahamas sample, except the large proportion of mollusks in No. 3 sand and of coralline algæ in No. 1 sand, the proportion of all madrepores, mollusks, and algæ is rather regular. The irregularity of the proportion of foraminifera is of course due to the fact that the entire individuals of this group tend to range between definite size limits and therefore predominate in corresponding size portions.

It is worth noting that in the Bahamas sample the regularity in proportion of combined coralline algæ and *Halimeda* is particularly great, though the proportion in No. 1 sand still remains high. This special regularity in the proportion of the combined algæ suggests that there have perhaps been errors in differentiating them from each other, one of the more probable errors in identification as pointed out above (p. 42).

The distribution of proportions therefore suggests greater error in identification in the Murray Island than in the Bahamas sample. Other considerations in favor of the Bahamas sample are that more experience was brought to it and that probably it was studied more painstakingly.

However, if the consideration of all these relationships leads to no definite conclusion as to the relative validity of the calculated compositions for the Murray Island and the Bahamas areas respectively, there is a relationship in the directly determined compositions of the different size portions of the Bahamas sample, as brought out in table 10, which, being based on accurate data, can be relied on, and it will therefore be considered first. It is the increase in proportion of calcium carbonate and decrease in proportion of magnesium carbonate with decreasing size of constituents. As the relative surface exposed to solution and reaction increases with diminution of size of particles of the same shape, this relationship would appear to be directly opposed to the theory that ocean water tends to increase the magnesia of calcareous material exposed to its action. The relation of calculated to directly determined compositions points in the same direction.

That no such effect is apparent in the Murray Island samples may be due to several different causes; for instance, to different chemical conditions in the waters in which they were immersed, which was only a few inches deep, whereas the Bahamas sample came from a depth of about 10 feet. Or this difference in depth may have led to an appreciable difference in temperature, or the material in the Murray Island localities may have been rapidly renewed by currents and wave action so that it had not had time to undergo any alteration.

None of these interpretations, however, does away with the disturbing similarity of the determined chemical compositions for the two areas. If we do not want to admit that it is due to similarity in original composition, implying that the count for the Bahamas sample is greatly in error, we must conclude either that it is accidental (which is not at all impossible), or that in view of the tendency toward chemical equilibrium which it is logical to assume must exist between ocean water and solid particles immersed in it, and in view of the general uniformity in the composition of open ocean water over the earth, the composition of immersed particles would tend to change so as to bring them to about the same chemical composition, however they may have differed in the beginning.

With these considerations in mind, the conclusion may be drawn that although the possible error of the method of investigation here employed may be greater than such slight chemical changes as those indicated by the results, those results suggest that *there has been relative decrease rather than increase of magnesium carbonate.*

CHEMICAL EVIDENCE ON THE RELATIVE SOLUBILITIES OF CALCIUM AND MAGNESIUM CARBONATES.

Though this conclusion is contrary to the most generally accepted beliefs[1] there is, as will be shown in the following pages, much evidence supporting it and it accords well with the ideas of R. C. Wells, of the U. S. Geological Survey, who has given considerable attention to the problems related to this question.[2] In conversation he says that although his experiments as well as Johnston's are inconclusive because they dealt with the hydrous carbonate of magnesium, which is much more soluble than the anhydrous compound, he nevertheless considers it quite possible in view of the incompleteness of experimental evidence and ignorance about the form in which magnesium carbonate occurs in organic skeletons, that magnesium carbonate will prove to be the more soluble under common shallow-water marine conditions. Wells points out that Skeats's conclusions, cited above, are misleading in several respects. First of all, as just stated, Wells's experiments, as well as others by Leather and Sen,[3] do not indicate that under usual atmospheric conditions calcium carbonate is more soluble than magnesium carbonate in ocean water. Furthermore, Skeats seems to confuse hydrostatic pressure with partial pressure of dissolved CO_2 at a certain depth of water.

Besides, Wells is inclined to think that in any case the range of pressure within these smaller depth limits would not reverse the relative solubilities of the two carbonates and that the magnesium carbonate may be the more soluble under most conditions in the upper layers of ocean waters. As there is, however, little or nothing known about the reactions of the actual carbonates involved, he suggests experiments with fragments of skeletons of organisms in actual ocean water, in which the only modification is a great increase in the amount of CO_2 in solution, that is, in its partial pressure, in order to get changes great enough to be readily observed.

In any case it must be borne in mind, as pointed out by Skeats,[4] that any observations are applicable only to the particular conditions of temperature, pressure, content of CO_2 in the water, other dissolved substances, form of the carbonates, possibly bacteria, and other factors under which they are made, and consequently, where natural conditions are involved, only to the particular area in question. It is largely failure to consider this fact, and in experimental work to obtain equilibrium, which has led to such apparently conflicting observations on the relative solubilities of calcium and magnesium

[1] Cf. E. W. Skeats, Amer. Jour. Sci., 4th ser., *45*, p. 199, 1918.

[2] Cf. R. C. Wells. Solubility of calcite in sea-water in contact with the atmosphere and its variation with temperature. Carnegie Inst. Wash. Pub. No. 213, pp. 316-318, 1918; Solubility of magnesium carbonate in natural waters, Jour. Am. Ch. Soc., *37*, No. 7, pp. 1704-1707, July, 1915. Cf. also, John Johnston. The solubility-product constant of calcium and magnesium carbonates. Jour. Am. Ch. Soc., *37*, No. 9, 2001-2020, Sept. 1915.

[3] See below, p. 61.

[4] Amer. Jour. Sci., 4th ser., *45*, p. 199, 1918.

carbonates under natural and experimental conditions. Without any pretense of completeness some of the principal published evidence is presented here. Observations and experiments dealing with the relative solution of the two carbonates will be considered first.

In 1875 Hoppe-Seyler[1] showed that very conflicting results had been obtained, both in experiments with acids on magnesian limestones and dolomites and from analyses of natural waters issuing from such rocks. Some solutions contained the two carbonates in equal molecular amounts, others contained calcium carbonate in excess. Hoppe-Seyler assumes a difference in purity of the rock. But the fact that no microscopic differentiation was made between magnesian limestone and true dolomite leaves this factor in the problem undefined.

Along the same lines Hall and Sardeson[2] found that springs issuing from rocks of the magnesian series of Wisconsin, Minnesota, and Iowa were richer in calcium carbonate, the percentage averaging nearly twice as high as of magnesium carbonate.

Scheerer[3] found that the powder of a limestone containing more than 9 per cent of magnesium carbonate when exposed for 30 hours to an active current of CO_2 in water yielded large amounts of calcium carbonate and only traces of magnesium carbonate. And when this same limestone and a dolomite were exposed for the same length of time to solution conditions as nearly the same as possible the limestone yielded about six times as much substance to the solution as the dolomite.

Roth,[4] bringing together various lines of evidence, shows that at certain pressures magnesium carbonate is more soluble than calcium carbonate in water saturated with CO_2. While stating that calcium carbonate is generally in larger amounts than magnesium carbonate in natural waters (a fact rather to be expected, since, according to Clarke,[5] the ratio in the earth's crust of CaO:MgO=4.86:3.74) he records[6] several occurrences where the opposite relation was found to hold. As regards true dolomite, Roth[7] cites several experiments in which water saturated with CO_2 at atmospheric pressure dissolved the magnesium and calcium carbonate of the mineral in almost exactly their original proportions, while at a pressure of 5 to 6 atmospheres the magnesia is the more soluble.[8] "Dolomitic" (i. e., magnesian) limestones[9] also in most cases yielded their carbonates to carbonated water in about the ratio in which they were present in the rock, but

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[1] Zeit. Deut. Geol. Gesel., *27*, Heft 3, pp. 495–530, 1875.
[2] Bull. Geol. Soc. Amer., *6*, p. 194, 1894.
[3] Neues Jahrb. f. Minn., etc., 1866, p. 11.
[4] Allgemeine und chemische Geologie, *1*, pp. 48, 50, 70, and 76, 1879.
[5] *Geochemistry*, 5th ed., U. S. Geol. Surv. Bull. 770, p. 34, 1924.
[6] Roth, op. cit., p. 50.
[7] *Idem.*, p. 52.
[8] Cf. Skeats, Amer. Jour. Sci., 4th ser., *45*, p. 199, 1918.
[9] Roth, op. cit., pp. 72-75.

with shorter exposure to the carbonated water magnesium carbonate was dissolved in relatively larger amounts. Acetic acid, on the other hand, generally extracted mainly the calcium carbonate from dolomitic limestones, but as the relative amounts of dolomite and uncombined carbonates were only calculated theoretically from the evidence of their relative solubilities, the result is inconclusive.

Roth refers[1] to an oft-quoted experiment of Bischoff[2] in which out of the residue from the evaporation of a mineral spring distilled water dissolved 28 times as much magnesium carbonate as calcium carbonate. Roth attributes this to the effect of other salts present in increasing the solubility of the magnesium carbonate,[3] but it is also quite probable that the magnesia was present as a hydrous carbonate.[4]

The porous or cavernous structure of dolomites has suggested relative enrichment in magnesium carbonate by selective removal of calcium carbonate in percolating waters,[5] but where the altered rock was originally coral-reef limestone these caverns may well be accounted for by the cavernous structure of the original reef resulting from spaces between coral heads. Högbom's observations[6] on calcareous marine sediments, showing an increase in ratio of magnesium carbonate to calcium carbonate with duration of suspension in ocean waters, are taken to indicate extraction of calcium carbonate by these waters.

In connection with Högbom's reference (cited by Clarke)[7] to stalactites from caverns in coral rocks of Bermuda which contained calcium in much higher ratio to the magnesium than the country rock, Clarke's further citation[8] of stalactites of hydrous magnesium carbonate in coal mines should be noted. In this connection Clarke also cites Jourdy's[9] observation that coordinated with a much lower percentage of magnesia in fossil than in living echinoderms, there is a frequent enrichment in magnesia of calcareous beds underlying those which contain the echinoderm remains. This seems to point pretty clearly to more solution of magnesium carbonate than of calcium carbonate from the echinoderm-bearing rock.

Approaching the problem from another side, namely, the relative precipitation of the two carbonates from solutions of both of them, the results, as brought out in Clarke's[10] review, are contradictory.

[1] Roth, op. cit., p. 75. [2] Lehrbuch der chem. u. physik. Geol. 2d ed., *1*, p. 214, 1863.
[3] Cf. Roth, op. cit., p. 51.
[4] Cf. above, p. 58, as to the greater solubility of the hydrous carbonate and below, p. 61, as to the likelihood of its separation from solution.
[5] See (e. g.) Clarke, *Geochemistry*, 5th ed., U. S. Geol. Survey Bull. 770, p. 576, 1924.
[6] See footnote 4, p. 52, and cf. Clarke, *Geochemistry*, 5th ed., U. S. Geol. Survey Bull. 770, p. 572, 1924.
[7] Clarke, *Geochemistry*, 5th ed., U. S. Geol. Survey Bull. 770, p. 574, 1924.
[8] *Idem.*, p. 578.
[9] Bull. Soc. Geol. de Fr., 4th ser., *16*, pp. 9-17, 1916.
[10] *Geochemistry*, op. cit., pp. 567-568.

Thus, Hoppe-Seyler[1] cites Gorup-Besanez, who found that the same waters that had dissolved the two carbonates from dolomites in equal molecular amounts, on evaporation in the air precipitated mainly calcium carbonate, indicating that under those conditions it was the less soluble. Scheerer[2] on the other hand claims to have obtained dolomite crystals on evaporation in the air of mixtures, in various proportions, of calcium and magnesium carbonates, before the single carbonates began to separate. Incidentally it is worth noting, as bearing on Wells's and Johnston's experiments (see p. 58, above, footnote 2), that both Scheerer[3] and Hoppe-Seyler[4] note that the magnesium carbonate was precipitated in a hydrous form. Both solution and precipitation from solution are considered by Leather and Sen,[5] in their experiments, as they based their work on equilibrium conditions. They worked at atmospheric pressure and at temperatures ranging between 20° and 39° C. Comparing the data obtained from their later experiments on $MgCO_3$ with those obtained from their earlier experiments on $CaCO_3$, they reach the following conclusion:

"1. The concentration of solution of $Mg(HCO_3)_2$ in respect of any specified partial pressure of CO_2 is from 5 to 15 times greater than that of the corresponding calcium salt."

That is to say, under these conditions the magnesium bicarbonate is the more soluble, which agrees in general with Wells's determinations.[6]

"4. Regarding the data obtained by others, Engel's[7] were obtained under so much higher pressures of CO_2—several atmospheres—that they are not comparable with ours. Treadwell and Reuter's[8] experiments, as was noticed in our memoir[9] on the calcium salt, were conducted under such imperfect conditions that supersaturation was to be expected."

From their work on the system $CaCO_3$, $MgCO_3$, H_2CO_3, H_2O, including dolomite, $CaCO_3$, calcium-bicarbonate solution, magnesium-bicarbonate solution, and $MgCO_3 \cdot 3H_2O$ they draw the following general conclusions:

"1. If a mixture of calcium and magnesium carbonates is subjected to the action of carbonic acid and water, the calcium carbonate is largely or wholly

[1] Zeit. deutsch. geol. Ges., *27*, p. 500, 1875.
[2] Neues Jahrb. f. Min., etc., 1866, pp. 11-12.
[3] Neues Jahrb. f. Min., 1866, p. 12, 3d line.
[4] Zeit. Deut. Geol. Gesel. *27*, p. 502, 3d line, 1875.
[5] I am indebted to notes made by Professor John Johnston while he was with the Geophysical Laboratory of the Carnegie Institution of Washington, for the following references:
J. W. Leather and J. N. Sen. The systems $CaCO_3$, CO_2, H_2O in contact with air, Mem. Dept. Agric. Ind., Chem. Ser., *1*, No. 7, pp. 117 to 131, Feb. 1909. The systems (*A*) water, magnesium carbonate, and carbonic acid; (*B*) water, calcium carbonate, magnesium carbonate, and carbonic acid. Same, *3*, No. 8, pp. 205-234, August 1914.
[6] See p. *58* above.
[7] Engel and Ville, Compt. Rend. vol. 93, p. 340; Engel, Ann. Chim. Phys., (6), vol. 13, p. 349
[8] Zeits. anorg. Chem., vol. 17, p. 200.
[9] Mem. Dept. Agri. Ind., Chem. Ser., vol. 1, No. 7.

prevented from dissolving, a fact which is in accordance with the indication of the law of mass action.

"2. Dolomite has been found by us, as by others, to dissolve in carbonic acid as such, but so far as we could ascertain the concentration does not depend only on that of the carbonic acid.

"3. Dolomite is protected from the action of carbonic acid to a great extent by the presence of calcium carbonate, and magnesium carbonate protects it completely.

"4. The addition of calcium carbonate to a solution of dolomite in presence of excess of carbonic acid seems to cause a slight precipitation of magnesium carbonate, but no explanation of this can be offered."

These results appear to be the most definite and conclusive relating to this problem that have been obtained. The first conclusion of the last set seems to fit in well with the fact indicated by my observations, given above, on coral sands. It is to be noted, however, that no solid $MgCO_3$ was used in this last set of experiments.

Ballό[1] has taken up the question of the equilibrium conditions of dolomite with a special view to the possibility of its formation from aqueous solutions at atmospheric pressures and temperatures and concluded that it could not form under those conditions.

As a third method of approach there are observations on reaction of solid calcium carbonate with magnesium salts in solution. Hoppe-Seyler[2] found that neither magnesium bicarbonate nor magnesium chloride solutions formed dolomite when allowed to stand under various conditions with an excess of calcium carbonate, and the same result was obtained when sea-water saturated with CO_2 was used.[3] The fact that some magnesia was taken up by the solid he ignores, because the solid was always completely soluble in cold dilute acetic acid. He concludes, probably rightly, that no dolomite was formed, but for the geologist the fact that some magnesia was taken up is nevertheless important, since, as Klements[4] suggested, a subsequent combination might take place. Scheerer,[5] on the other hand, found that when CO_2 was passed for 48 hours through a solution of magnesium carbonate in the presence of finely powdered chalk, almost all the magnesia entered the solid phase, and according to Clarke,[6] this observation had been made previously by other chemists. Observations supposed to bear on this process in nature are numerous and form the basis of the entire theory of dolomitization by ocean water.[7] I know of only one observation pointing in the other direction; that is Hoppe-Seyler's observation[8] that the chalk around the

[1] Rodolphe Ballό. Contributions à la théorie de la formation de la dolomie, Földtani Közlöny, Hungarian Geol. Soc., *44*, pp. 136-145, 1914; pp. 520-524, summary p. 548, 1914; *45*, pp. 286-292, 1915.

[2] Zeit. deutsch. geol. Gesel., *27*, p. 500, 1875.

[3] Idem., p. 502.

[4] Cited by Clarke, *Geochemistry*, op. cit., p. 568.

[5] Neues Jahrb., 1866, p. 12.

[6] *Geochemistry*, op. cit., p. 568.

[7] Cf. Skeats, Amer. Jour. Sci., 4th ser., *45*, pp. 185-200, 1918.

[8] Zt. deut. geol. Gesel., *27*, p. 501, 1875.

North Sea is not in the least enriched by its contact with that body of water. That the coldness of the water of the North Sea may be a factor in this result must be recognized.

A fourth line of evidence is afforded by a comparison of the weathering residues of magnesian limestones with the fresh rock. Here too the results are divergent and inconclusive. Roth[1] gives a considerable amount of evidence on this. In volume 1 he compares the leached and unleached carbonates of "dolomitic" (i. e., magnesian) limestones and shows a great enrichment in magnesium carbonate in the leached residue. In volume 3 he discusses the residual clays left by more complete solution of magnesian limestones. Citing results of analyses of two occurrences, by Katzer, he shows that in both there was a decidedly greater relative removal of magnesium carbonates, but remarks that "these results do not agree with other observations." Two American analyses by Riggs and Hillebrand reproduced by Roth point to relatively greater solution of calcium carbonate. Two sets of analyses given by Merrill[2] indicate, when recalculated, an almost equal proportionate solution of the carbonates in one case and an only slightly greater solution of lime in the other, but he also mentions[3] that the magnesia from the decomposition of magnesian silicates is sometimes removed in greater relative proportions than the lime. To these results Stockdale[4] adds calculations from two analyses of residual clays which, compared with the analyses of the original limestone, show an almost complete removal of lime with acquisition [sic.] of magnesia, and from three analyses of clays on stylolite seams (which he proves pretty conclusively are solution products), two of which indicate a slightly greater removal of calcium carbonate and the other of magnesium carbonate when compared with the rock containing them.

From all this conflicting evidence it is clear that observations have not been made under conditions of complete equilibrium free from extraneous modifying factors, with substances of definitely known mineralogical composition and bearing in mind the possible participation of bacteria. Until that has been done for a wide range of conditions it will be impossible to form an opinion of what is to be expected in any particular natural environment.

RELATIONS OF CALCIUM SULPHATE AND PHOSPHATE IN THE SAMPLE.

Another point worth noting is that in both the Murray Island sample[5] and in this the calculated compositions show more calcium sulphate and phosphate than the chemical analysis. As calcium

[1] Allgemeine und chem. geol., *1*, pp. 75 and 76-79, 1879; *3*, pt. 2, pp. 217-218, 1893.
[2] Rocks, rock-weathering, and soils, pp. 217, 219, 1906.
[3] Idem., p. 225.
[4] *Styolites*, Indiana University Studies No. 55, vol. 9, pp. 71, 75-77, Dec. 1922.
[5] Cf. Carnegie Inst. Wash. Pub. No. 213, p. 262, 1918.

sulphate is generally considered much more soluble under marine bottom conditions than calcium and magnesium carbonate, its disappearance or reduction in relative amount is what would be expected. As regards calcium phosphate, the situation is much the same as with magnesium carbonate; that is to say, the evidence is conflicting and inconclusive. The abundance of phosphatic skeletons in submarine phosphate deposits has been accounted for[1] as due to solution of the more purely carbonate skeletons, but, as pointed out by Skeats, for magnesium and calcium carbonate there may be a reversal of the process under certain conditions of temperature, pressure, etc.

SUGGESTIONS FOR FUTURE INVESTIGATIONS.

If this approach to the important problem of the effect of sea-water on particles submerged in it yields inconclusive evidence, there are, I think, several simpler and more direct methods of investigation which seem to promise accurate and reliable results and, in so far as they bear on the area and materials involved in this study, it seems worth while to outline some of them here.

One of the most obvious that suggests itself is direct experiment under the actual natural conditions by submerging part of a weighed and analyzed lot of fragments of the skeleton of a single species in the bottom in some container that would permit free circulation and itself take no possible part in the reaction,[2] or if this would require too much time for appreciable results some such laboratory experiment as that suggested by Wells (p. 58) might be resorted to; or pumped ocean water might be made to circulate through a lot of the crushed skeletal material in the laboratory under conditions of pressure and temperature existing at the ocean bottom. In any case the natural conditions and substances, including any bacterial floras that may be present, should be as closely adhered to as possible.

Certain forms like the foraminifera, *Halimeda*, etc., can be specifically recognized in a sand. Lots of these selected from a bottom sample might be compared chemically with skeletons taken from living material in the same area. This would also bring out the effect of original composition on any changes undergone and show whether there is a tendency toward a definite composition, as surmised above (p. 57).

Gross analyses might be made from different layers of a sample taken with a sounding-tube penetrating to some depth into these reef sands and representing different durations of exposure to ocean

[1] C. W. Hayes. *The Tennessee phosphates*, 16th Ann. Rept. U. S. Geol. Survey, pt. 4, p. 623, 1895. For a summary review of the probable conditions involved see Marcus I. Goldman. *Basal glauconite and phosphate beds*, Science, *56*, pp. 171-173, Aug. 11, 1922.

[2] For some of the obstacles introduced into such experiments by invasions of foreign organisms cf. A. G. Mayor, *Submarine solution of limestone in relation to the Murray-Agassiz theory of coral atolls*, Proc. Nat. Acad. Sci., *2*, pp. 28-30, 1916.

water; and specific forms, as in the preceding suggestion, but taken from different layers of the tube sample, might be compared.

As shown above, many purely laboratory experiments relating to this problem have been tried and many more could probably be devised by competent physical chemists, but unless these very closely approximate natural conditions they will never be thoroughly conclusive, so that it seems preferable to resort to conditions as they actually exist in nature.

Samples collected for this work, whether they are to be studied by the method used in preparing this report or by some of those suggested, should be large—at least a kilogram, dry—so that they may yield portions or constituents ample for all the purposes considered above.

SUMMARY.

The results of a count of the different constituents, mainly calcareous skeletons, composing the sand from the shelf back of the reef off the northeast end of Andros Island in the Bahamas are presented. The methods of conducting the count are described. From the count the chemical composition of the sands is calculated and this is compared with the composition as directly determined. Within the limits of accuracy permitted by the method of investigation the results indicate a relative decrease in the amount of magnesium carbonate, calcium sulphate, and calcium phosphate ($Ca_3P_3O_8$). It is shown that this result is not necessarily inconsistent with previous chemical investigations. Lines of investigation likely to yield more direct and reliable results bearing on this chemical problem are suggested.

APPENDIX.

COMPOSITION OF A FRAGMENT OF ACROPORA EXPOSED FOR 34 YEARS TO OCEAN WATER.

After this report was completed an opportunity was afforded to test the effect of exposure of skeletal material of known composition for a known length of time to the action of surface ocean water. Dr. T. W. Vaughan kindly supplied a piece of one of the skeletons of *Acropora* from south of Loggerhead Light, Tortugas, Florida, killed by the "Black Water" of 1879,[1] and collected by him June 9, 1913.

Before analysis a great deal of the outer part (probably about half the radius) had to be ground away because it was so heavily incrusted and penetrated by organic growths (calcareous algæ, worm tubes, bore holes, etc.). As some of the bore holes penetrated to the very center, it was not possible to eliminate them entirely, but there were few left and they showed little or no incrustation, so that their effect may probably be ignored.

[1]See Year Book, Carnegie Inst. Wash. No. 9, for 1910, p. 135.

An analysis by Mr. J. G. Fairchild, of the U. S. Geological Survey, gave the following result:

	Per cent.
CaO	53.92
MgO	0.11
SO_3	0.50
P_2O_5	Trace
Insol.	0.53

Clarke[1] gives the following analysis of *Acropora cervicornis:*

	Per cent.
CaO	52.47
MgO	0.20
SO_3	(?)
P_2O_5	Trace

Here too the differences in magnesia content are too slight, in view of the uncertainties involved, to permit any definite conclusion to be drawn from them. But if it is not possible to assert that there has been a loss of magnesia in the *Acropora* exposed for 34 years to ocean water, there has, at least, been no appreciable increase. To arrive at conclusions at all convincing, even on so simple a problem as this, it will be necessary to compare very carefully made analyses of a number of specimens of fresh and of exposed material from the same general area.

[1]U. S. Geol. Survey Prof. Paper 124, p. 7, column 18, 1922.

REPORT ON A BACTERIOLOGICAL EXAMINATION OF "CHALKY MUD" AND SEA-WATER FROM THE BAHAMA BANKS.

By N. R. Smith.
Bureau of Plant Industry, U. S. Department of Agriculture.

REPORT ON A BACTERIOLOGICAL EXAMINATION OF "CHALKY MUD" AND SEA-WATER FROM THE BAHAMA BANKS.

By N. R. Smith.

The average number of bacteria found in the chalky mud and growing upon special salt media was 565,000 per wet gram. Anaerobic plates showed a scant growth, and after exposure to the air the colonies increased in size. There was no production of H_2S on media which contained high amounts of inorganic sulphates, although the presence of H_2S was easily determined in the mud. It is likely that organic sulphur and anaerobic conditions are prerequisites for H_2S production.

All the colonies on three plates were picked off and put into media for pure-culture work. A comprehensive and critical study of their activity showed them to belong to three large groups based upon their biochemical relations.

Group I.	Denitrifiers:	Ps. calcis type.	
Group II.	Ammonifiers:		
A.	Vibrios.	Strong ammonifiers.	
B.	Vibrios.	Weak ammonifiers.	
C.	Rod forms	Weak ammonifiers.	Gram negative.
D.	Rod forms	Weak ammonifiers.	Gram positive.
Group III.	Inactive forms.		

A similar study was made of the bacteria in a sample of sea-water taken in the Bahamas. The number of organisms isolated and studied and the percentage of each group found in the mud and water are given in table 1, together with duplicate studies made after 17 months storage of the two samples at about 20 degrees centigrade.

Table 1.

Sample.	Total isolations.	Per cent of each group of bacteria present.						Average per gram or c.c.
		I.	II-A.	II-B.	II-C.	II-D.	III.	
Mud.....	111	17.1	49.5	2.7	17.1	0	13.5	565,000
Water.....	97	9.2	0	19.6	35	19.6	16.5	175,000
Repeated after 17 months' storage.								
Mud.....	155	27.1	52.9	0	1.9	1.2	17	403,000
Water.....	40	25	0	0	30	2.5	42.5	3,200

The predominating type of organisms found in the mud was a *Vibrio* which produces strong ammonia from organic matter. Next in number come the denitrifiers and the weak ammonifiers. A comparison of the analyses made when the mud was received and after 17 months storage shows very little change in the relationship of the groups to each other. On the other hand, the storage of the water had a very upsetting influence on that relationship. The denitrifiers and the inactive forms increased in proportion, while the weak ammonifying vibrios and the gram positive rods decreased. The total numbers dropped from 175,000 to almost 3,000, in contrast to the mud, which showed only a slight decrease.

The character of the flora of the mud and of the sea-water is quite different. About half of the organisms in the mud are strong ammonifying vibrios and none of these have been found in samples of sea-water. The weak ammonifying vibrios, however, are much more prevalent in the water, as are also the gram positive weak ammonifiers. The number of denitrifying bacteria in the mud is about double that found in sea-water, and while in the case of the mud the denitrifying bacteria are one of the three most numerous groups, in the case of the water they are next to the lowest. If the subdivisions of group II are considered together, they represent about 70 per cent of the total bacteria of the mud and 75 per cent of the total in sea-water. This high percentage would seem to be significant, but whether it would hold in other samples of mud or water, it is

TABLE 2.

Nutrients added.	Inoculum.	Calcite.
Natural sea-water.		
1. Peptone 0.2 p. ct.; KNO_3, 0.2 p. ct.	Crude cultures	Many crystals.
2. Do	Group I	Do.
3. 2 gm. cooked egg albumen	Crude cultures	Crystals.
4. Do	Do	Do.
5. Do	Group I and II A	Many crystals.
6. Sterile mud in dialyzing tube	Do	Few crystals.
7. Do	Crude cultures	Very few crystals.
8. Do	None	No crystals.
Artificial sea-water.		
10. Peptone 0.2 p. ct.; KNO_3, 0.2 p. ct.	Group I	Few crystals.
11. Do	Crude cultures	Many crystals.
12. KNO_3, 0.2 p. ct	Do	Few crystals.
13. Peptone 0.2 p. ct.; KNO_3, 0.2 p. ct. agar 0.2 p. ct.	Do	Many crystals and aggregates.
14. Do	Group I	Do.
15. Do	Groups I and II A	Do.

hard to say. Although some of the previous samples of water have given practically pure cultures of the denitrifying group, other groups may have been present and have been overlooked if they were in those particular samples. Of course, the denitrifying group also produces ammonia, but it comes mostly from the reduction of the nitrates rather than from the splitting up of the proteins.

The precipitation of calcium carbonate in natural and artificial sea-water by mixed crude cultures from the mud and by pure cultures is given in table 2. Various sources of food for the bacteria are indicated. In each flask a dialyzing tube containing calcium sulphate was suspended to keep a supply of calcium in solution.

It is interesting that in 8 no crystals of calcite formed, while 6 and 7 inoculated with a mixture of groups I and II A and a crude culture respectively, showed some calcite. The amount was small in comparison with some of the others. This should be expected, for in this case the only nutrients for the bacteria had to come from the sterilized mud. The greatest amount of calcite is usually formed when both peptone and nitrate are added, but may be formed when either is alone, the nitrate alone being worse than peptone alone.

The addition of agar to the nutrient solution seemed to favor the production of calcite and especially the formation of aggregates of crystals in 13, 14, and 15. Previous experiments using agar and acacia failed to show this beneficial effect.

One objection might be raised to the above experiment as a whole, and that is that a dialyzing tube of calcium sulphate was suspended in each flask. Also, only groups I and II A were used for the pure-culture inoculations. The following experiment, therefore, was set up and results are given in table 3. Sea-water with 0.02 per cent K_2HPO_4 was used as a base, the nutrients being as indicated in the table. Plus marks indicate production of calcite and zero indicates none.

TABLE 3.

Nutrients.	I.	II A.	II B.	II C.	III.
Peptone 0.2 p. ct.	0	+++	0	0	0
Peptone 0.2 p. ct., KNO_3 0.2 p. ct.	+	+++	0	0	0

As can be seen from a glance at the table, group II A in pure culture precipitated by far the greatest amount of calcite, and group I only precipitated calcite when nitrates were present. Even then the amount was comparatively small. A rough analysis of the solution in the flasks of group II A after the precipitation of calcite showed only about half the amount of calcium of the control flask.

From the foregoing, the following points seem to be the most important.

1. The bacteria of sea-water or bottom mud from the chalk bank may be grouped into 6 main groups according to their physiological activities.

2. Calcite is formed from calcium sulphate as a result of the growth of the bacteria; the more plentiful the food, the better is the chance for the formation of calcite. Bottom mud provides a nutrient for production of small amount of calcite.

3. Agar in low percentage favors the formation of larger accumulations of crystals of calcite.

4. Calcite is formed in natural sea-water by pure cultures if organic matter is added.

RECENT FORAMINIFERA FROM PORTO RICO.

By Joseph A. Cushman.

With one plate.

RECENT FORAMINIFERA FROM PORTO RICO.

By Joseph A. Cushman.

Early in 1921, while at Porto Rico, I took the opportunity to collect shallow-water foraminifera, especially in San Juan Harbor. The only records from Porto Rico were published by the late Dr. James M. Flint, who examined a few of the *Fish Hawk* collections. Most of these were in outside waters, although at comparatively shallow depths. The number of species recorded by Flint is small.

As this region is so little known, the comparison with the shallow-water fauna of the Tortugas Region and with Jamaica gives data valuable from the point of view of distribution, the apparent lack of certain species in the shallow water of Porto Rico being fully as interesting as the presence of many common ones. In the work commenced with the late Dr. Alfred G. Mayor at Montego Bay, Jamaica, and later carried on at the Tortugas, it was hoped by gaining a knowledge of the shallow-water foraminifera of the general West Indian region that data might be made available for use as criteria in problems of sedimentation, and also as to depths at which Tertiary sediments of the Coastal Plain and West Indian regions were deposited. It was with this end in view, as well as to gain a knowledge of the Porto Rican forms, that the collections were made and studied.

In order to avoid duplication of data, references are given to the Tortugas paper (Carnegie Inst. Wash. Pub. 311, 1922) whenever possible. When the species was not recorded from the Tortugas, reference is made to my paper on the Jamaican foraminifera (Proc. U. S. Nat. Mus., vol. 59, 1921, pp. 47 et seq.). The stations and data are as follows:

No. of station.	Location.	Depth, feet.
1	San Juan Harbor, in ship channel south of docks	30
2	midway between San Juan and Catano	16
3	Anegada shoal	6
4	Largo shoal	7
5	outside entrance to Miraflores Bay	20
6	at entrance to Miraflores Bay	9
7	in Miraflores Bay	15
8	in channel between Miraflores Bay and Cano de San Antonio, between mangrove islands.	12
9	Ponce, in very shallow, rather stagnant water	3

The stations in San Juan Harbor represent successive stages away from the comparatively open water of the main harbor to the rather

stagnant and very warm waters of the mangrove area to the eastern end of the harbor.

Except for the moat at Fort Jefferson at the Tortugas, this Porto Rican material is from a more inclosed area than the other West Indian material recorded. This character is at once apparent by the abundance of the small form of *Rotalia beccarii*, which was found only in rather stagnant, warm waters at the Tortugas. The species follow.

Family LITUOLIDÆ.

Ammobaculites reophaciformis Cushman.

Ammobaculites reophaciformis Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 20, pl. 1, fig. 1.

Specimens from station 2 only. Rare in shallow water both at Tortugas and Jamaica.

Family TEXTULARIIDÆ.

Textularia agglutinans d'Orbigny.

Textularia agglutinans d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 22, pl. 1, fig. 6.

Occurred only at station 1. Common at Jamaica and abundant at the Tortugas. Recorded by d'Orbigny from Cuba, St. Thomas, Martinique, and Jamaica.

Textularia candeiana d'Orbigny.

Textularia candeiana d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 23, pl. 2, fig. 2.

Specimens only at station 6. At Jamaica the species occurred only at the deeper stations. In the Tortugas it was not nearly as common under 5 fathoms as in somewhat deeper water. D'Orbigny's records were from Cuba, Martinique, and St. Thomas.

Bolivina limbata H. B. Brady var. costulata Cushman.

Bolivina limbata H. B. Brady var. *costulata* Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 26, pl. 3, fig. 8.

This variety was described from the Tortugas material, and the occurrence of it at Porto Rico at station 4 probably means that it is to be looked for in the general West Indian region in comparatively shallow water.

Bolivina mayori Cushman.

Bolivina mayori Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 27, pl. 3, figs. 5, 6.

Although described from the Tortugas region, this species occurs in shallow water in the Pacific, and it is not surprising to find it even rarely at Porto Rico. A single specimen, probably young, from station 7.

Verneuilina spinulosa Reuss.

Verneuilina spinulosa Reuss, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 28, pl. 3, fig. 11.

Occurs at station 1 only. It was not common either at the Tortugas or Jamaica, although in the Pacific it is very abundant in shallow water.

Virgulina punctata d'Orbigny.

Virgulina punctata d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 31, pl. 3, fig. 9.

No specimens were obtained in the San Juan collections, but it occurred at Ponce, station 9. It is very abundant in the Tortugas region, but was rare at Jamaica. D'Orbigny originally described the species from Cuba and Jamaica.

Family LAGENIDÆ.

Polymorphina vitrea d'Orbigny.

Polymorphina vitrea d'Orbigny, Cushman, Proc. U. S. Nat. Mus., vol. 59, 1921, p. 54, pl. 12, fig. 4; text-fig. 2.

A single specimen from station 2 is very close to the specimens figured by d'Orbigny. It was not found at the Tortugas. In the Jamaican collections this was the only representative of the family. The Porto Rican collections gave but two. The Lagenidæ are certainly very rare in shallow water in the tropical Atlantic, and the few from the Tortugas were mainly at the greater depth.

Siphogenerina raphanus (Parker and Jones).

Siphogenerina raphanus (Parker and Jones) Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 35, pl. 5, fig. 5.

There are a number of specimens from station 4. The species was not obtained at all from Jamaica, and single specimens at but two stations in the Tortugas collections. The species is widely distributed in the Indo-Pacific.

Family GLOBIGERINIDÆ.

Globigerina rubra d'Orbigny.

Globigerina rubra d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 36, pl. 14, figs. 1, 2.

It is interesting to note that both species of *Globigerina* are very rare, and occur at the two stations nearest to open water near the mouth of the harbor. Apparently the surface water outside the harbor does not make its way in as far as the other stations. Both species were described by d'Orbigny from shallow water of the West Indies.

Globigerina rubra occurred at station 1.

Globigerina dutertrei d'Orbigny.

Globigerina dutertrei d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 36, pl. 4, figs. 8, 9.

Rare at station 2.

Family ROTALIIDÆ.

Spirillina vivipara Ehrenberg.

Spirillina vivipara Ehrenberg, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 37, pl. 5, fig. 7.

Several specimens from station 4. Not noted from Jamaica, and rare at the Tortugas.

Discorbis mira Cushman.

Discorbis mira Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 39, pl. 6, figs. 10, 11.

I described this species from the Tortugas, where it occurred as one of the common species of that region. It was found at three of the stations in San Juan Harbor, 4, 5, and 8; rather common at station 5.

Discorbis auberii (d'Orbigny).

Discorbis auberii (d'Orbigny), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 40.

This is one of the species described by d'Orbigny from the shallow sands of the West Indian region, recorded from Cuba and Martinique. It was rare both at Jamaica and the Tortugas. Specimens occurred at station 2, San Juan Harbor, and station 9, Ponce.

Discorbis subauracana Cushman.

Discorbis subauracana Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 41, pl. 7, figs. 1, 2.

Described from the Tortugas, where it was common. It occurred at Porto Rico at station 4.

Discorbis valvulata (d'Orbigny).

Discorbis valvulata (d'Orbigny), Cushman, Proc. U. S. Nat. Mus., vol. 59, 1921, p. 59, pl. 14, figs. 4, 5.

D'Orbigny described this species from Martinique. It was not found in the Tortugas material, but did occur at one station at Jamaica. Specimens occurred at 2 Porto Rican stations, 1 and 5. The figure given by d'Orbigny in 1839 for this species is a very good one.

Planorbulina mediterranensis d'Orbigny.

Planorbulina mediterranensis d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, p. 45, pl. 6, figs. 1, 2.

A specimen from station 4 somewhat resembles *P. acervalis* H. B. Brady, and revives the question as to the possible identity of d'Orbigny's *P. vulgaris* with this species. The other specimen is more clearly of the form of *P. mediterranensis*, but is evidently a young specimen. It is also known from the Tortugas.

Truncatulina rosea (d'Orbigny).

Truncatulina rosea (d'Orbigny), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 46, pl. 14, figs. 3-5.

This very characteristic West Indian species occurred at stations 1 and 8 only. Flint recorded it from Porto Rico, but only at the shallowest of his stations, 4 to 7½ fathoms.

Truncatulina candeiana (d'Orbigny).

Truncatulina candeiana (d'Orbigny), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 47, pl. 6, figs. 7-9.

Two specimens from station 1 are the only records for this species in the Porto Rican collections. It occurred at the Tortugas and Jamaica. D'Orbigny's original specimens were from Cuba.

Siphonina pulchra Cushman.

Siphonina pulchra Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 49, pl. 7, figs. 11, 12.

There are specimens from stations 4 and 6. It was originally described from the Miocene of Cuba, and was recorded from the Tortugas region.

Pulvinulina semipunctata Cushman.

Pulvinulina semipunctata Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 51, pl. 8, figs. 5, 6.

Originally described from the Tortugas region, this species is widely distributed in the tropical Atlantic and Pacific. Specimens were fairly common at station 4, San Juan Harbor, and station 9, at Ponce.

Pulvinulina incerata Cushman.

Pulvinulina incerata Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 51, pl. 9, figs. 1-3.

The only previously known locality is the Tortugas. There it occurred in considerable numbers in deeper water outside the reef, but rarely inside in very shallow water. There are two specimens from Porto Rico, station 5.

Rotalia beccarii (Linnaeus) var. tepida, new variety.

(Plate 1.)

Test small, almost equally biconvex, the dorsal side slightly more than the ventral, chambers 6 or 7 in the last-formed whorl; peripheral margin rounded; sutures slightly limbate above, ventrally much depressed; toward the umbilicus the chambers separated, forming angular, open spaces, the ends of the chambers extended to a point; wall smooth, finely punctate; aperture a narrow slit beneath the inner angle of the last-formed chamber, often supplemented by a nearly circular, small opening near the base of the ventral face of the last-formed chamber.

Diameter not over 0.35 mm.

Type specimens from station 2, San Juan Harbor. It also occurred commonly at stations 1, 4, 5, 6, and 8, at San Juan, and station 9, at Ponce. It is one of the most common and widely distributed forms in the Porto Rican samples. As these stations are all in warm protected waters, it is interesting to note that the same form found at the Tortugas occurred only at three stations, two in the warm, shallow, stagnant water of the moat at Fort Jefferson, Garden Key, and the other on Long Key in a tide pool where the water at low tide was very warm.

Family NUMMULITIDÆ.

Nonionina grateloupi d'Orbigny.

Nonionina grateloupi d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 55, pl. 9, figs. 7, 8.

This is a widely distributed species in the West Indian region. D'Orbigny originally described it from Cuba, Jamaica, and Martinique. I have had it from Jamaica and the Tortugas, and as a fossil from the later Tertiary of Cuba and Santo Domingo. Porto Rican specimens are from stations 4 and 5.

Nonionina sloani d'Orbigny.

Nonionina sloani d'Orbigny, in De la Sagra, Hist. Fis. Pol. Nat. Cuba, 1839, "Foraminiferes," p. 46, pl. 6, figs. 6, 7; Cushman, Carnegie Inst. Wash. Pub. 291, 1919, p. 48.

Specimens which may be referred to this species are from station 1. D'Orbigny's specimens were from Cuba, Jamaica, and Martinique. I have recorded it from the late Tertiary of Cuba and Santo Domingo.

The species is more compressed than the preceding, *Nonionina grateloupi*.

Polystomella poeyana d'Orbigny.

Polystomella poeyana d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 55, pl. 9, figs. 9, 10.

This is by far the commonest species of the genus in the shallow water of the West Indian region. It was common at the Tortugas and Jamaica, and is present in the Porto Rican collections from stations 1, 2, 4, 5, 6, 7, 8, and 9. D'Orbigny's original material was described from Cuba and Jamaica.

Polystomella discoidalis d'Orbigny.

Polystomella discoidalis d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 56, pl. 10, figs. 3, 4.

Specimens occurred at station 1, at San Juan, and station 9, at Ponce. It was described by d'Orbigny from shore sands of Cuba and Jamaica, and it is common at the Tortugas.

Polystomella lanieri d'Orbigny.

Polystomellalanieri d'Orbigny, Cushman, Proc. U. S. Nat. Mus., vol. 59, 1921, p. 61, pl. 14, figs. 12, 13.

Very typical specimens are present in the collections from stations 4, 5, 8, and 9. I did not find the species in the Tortugas region, but it was in the material from Jamaica, and in the late Tertiary of Cuba and Santo Domingo. The original material of d'Orbigny was from shore sands of Cuba.

Polystomella advena Cushman.

Polystomella advena Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 56, pl. 9, figs. 11, 12.

This species was described from the Tortugas region, and occurs also at Samoa. It is probably widely distributed in the West Indies and Indo-Pacific in shallow water. Porto Rican specimens were from stations 4 and 8.

Amphistegina lessonii d'Orbigny.

Amphistegina lessonii d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 57.

Specimens of *Amphistegina* are common at stations 4, 7, 8, and 9. As noted in the Tortugas paper, all of the specimens are small, and this may prove to be a different species from *A. lessonii*.

Family MILIOLIDÆ.

Cornuspira involvens Reuss.

Cornuspira involvens Reuss, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 58.

Specimens are rare in the Porto Rican material, occurring only at stations 4 and 7. It occurs both at Jamaica and the Tortugas.

Spiroloculina grateloupi d'Orbigny.

Spiroloculina grateloupi d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 59.

This is apparently a rare species in the West Indian region. There are single specimens from stations 2 and 5. It was not common at the Tortugas and not found at Jamaica.

Spiroloculina antillarum d'Orbigny var. angulata Cushman.

Spiroloculina antillarum d'Orbigny var. *angulata* Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 62.

No specimens of the typical form of the species were found, and only two of the variety at station 4. It is fairly common at Jamaica and the Tortugas, and widely distributed in the shallow, coral-reef areas of the Indo-Pacific.

Spiroloculina arenata Cushman.

Spiroloculina arenata Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 62.

I originally described this species from Jamaica, and later found it to be very common in the Tortugas region. It has occurred in the Porto Rican collections at stations 4 and 6.

Vertebralina cassis d'Orbigny var. mucronata d'Orbigny.

Vertebralina cassis d'Orbigny var. *mucronata* d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 63.

A single specimen from station 4 is the only Porto Rican record. It was common both at Jamaica and the Tortugas.

Quinqueloculina agglutinans d'Orbigny.

Quinqueloculina agglutinans d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 63.

Specimens occurred in considerable numbers at station 8 only. It occurred at all the stations in the Tortugas region and at several at Jamaica. It is known from the Bahamas and the coast of Florida. D'Orbigny's original material was from Jamaica and Cuba.

Quinqueloculina bidentata d'Orbigny.

Quinqueloculina bidentata d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 64.

From previous records this is not nearly so common as the preceding, *Quinqueloculina agglutinans*, either at Jamaica or the Tortugas. In the Porto Rican collections it is the most common species of the genus, occurring at stations 4, 6, 7, and 8; common at all of them. D'Orbigny's original specimens were from Cuba.

Quinqueloculina alveoliniformis (H. B. Brady).

Quinqueloculina alveoliniformis (H. B. Brady), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 64.

The few specimens from Porto Rico, stations 6 and 7, show the same characteristics as material from Jamaica and the Tortugas, namely, a much shorter, thicker form than specimens from the Indo-Pacific.

Quinqueloculina lamarckiana d'Orbigny.

Quinqueloculina lamarckiana d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 64.

Two specimens from station 4 are the only records from the Porto Rican collections. It is abundant at the Tortugas and Jamaica. D'Orbigny's original material was from Jamaica and Cuba.

Quinqueloculina laevigata d'Orbigny.

Quinqueloculina laevigata d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 65, pl. 13, fig. 2.

Specimens from stations 6 and 7 are referred to this species, as were those from the Tortugas.

Quinqueloculina candeiana d'Orbigny.

Quinqueloculina candeiana d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 65, pl. 13, fig. 1.

Next to *Q. bidentata* this is the most abundant species of the collections, occurring in considerable numbers at stations 1, 2, 3, 5, and 9. The species was common at but one of the Tortugas stations, and did not occur in the collections from Jamaica. Its occurrence in such numbers at Porto Rico is all the more noteworthy.

Quinqueloculina poeyana d'Orbigny.

Quinqueloculina poeyana d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 66.

This is a common species in the West Indian region and well characterized. It occurred at Porto Rico at stations 4, 6, 7, and 9.

Quinqueloculina polygona d'Orbigny.

Quinqueloculina polygona d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 68.

A single specimen from station 1 is the only record from Porto Rico. D'Orbigny described it from Jamaica and Cuba, and I have had specimens from Jamaica and the Tortugas.

Quinqueloculina crassa d'Orbigny.

Quinqueloculina crassa d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 342, 1924, p. 62, pl. 23, fig. 7.

This variety, which has a wide distribution in the Indo-Pacific, is apparently present at Porto Rico, although the latter specimens have a somewhat sharper edge. It occurred at stations 4, 6, and 7.

Articulina sagra d'Orbigny.

Articulina sagra d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 70.

A single specimen from station 4 is the only record from Porto Rico. It was rare both at the Tortugas and Jamaica. D'Orbigny's original material was from Cuba, Jamaica, and Martinique.

Hauerina bradyi Cushman.

Hauerina bradyi Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 71.

Specimens of this widely distributed, tropical species occurred at stations 4, 6, and 7. It is known from Jamaica and the Tortugas and elsewhere in the West Indian region as well as in coral-reef conditions in the Indo-Pacific.

Hauerina ornatissima (Karrer).

Hauerina ornatissima (Karrer), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 72.

This has been one of the finds of the West Indian region. The species originally described by Karrer from the Kostej in the Banat has been known as a species of shallow water of the Indo-Pacific. It was found first in the West Indian region at Jamaica, later at the Tortugas, and now at a single station, 6, at Porto Rico.

Triloculina trigonula (Lamarck).

Triloculina trigonula (Lamarck), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 72.

Rare specimens of the form noted from Jamaica and the Tortugas have occurred at stations 1, 2, 7, and 8.

Triloculina circularis Bornemann.

Triloculina circularis Bornemann, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 73.

This species, which was very common both at Jamaica and the Tortugas, is much less common at Porto Rico, occurring at stations 2, 4, and 8.

Triloculina rotunda d'Orbigny.

Triloculina rotunda d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 73.

Specimens occurred at stations 7, 8, and 9, being abundant at station 8. These three stations are all in very protected areas. It occurred at all the stations in the Tortugas, and was not noted from Jamaica.

Triloculina transversestriata (H. B. Brady).

Triloculina transversestriata (H. B. Brady), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 74.

This is another species of the Indo-Pacific which has recently been recorded in the West Indian region. Heron-Allen and Earland record it from Havana,

Cuba. I had a single specimen each in the Jamaican and Tortugas collections. There is a single specimen from Porto Rico at station 7.

Triloculina planciana d'Orbigny.

Triloculina planciana d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 74.

D'Orbigny originally described this species from Cuba and Jamaica. I have had typical specimens from Jamaica and the Tortugas. At Porto Rico it seems to be rare, occurring only at station 8.

Triloculina fichteliana d'Orbigny.

Triloculina fichteliana d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 75.

A single specimen from station 8 is of the form figured by d'Orbigny, and which seems to be characteristic of the West Indian region, but unlike many of the figures published by later authors. The original material of d'Orbigny was from Cuba and Jamaica. It occurred in my own collections from Cuba and Jamaica.

Triloculina bicarinata d'Orbigny.

Triloculina bicarinata d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 76, pl. 12, fig. 7.

This species originally described from Cuba, and which I have recorded from the Tortugas region, occurred at station 8 at Porto Rico. It is probably widely distributed in the West Indies.

Triloculina labiosa d'Orbigny.

Triloculina labiosa d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 77, pl. 12, fig. 1.

Originally described by d'Orbigny from shore sands of Cuba, this species is now known from both the West Indian and Indo-Pacific regions. I had it from Jamaica and the Tortugas, but it is apparently rare at Porto Rico, occurring only at station 8.

Biloculina subspherica d'Orbigny.

Biloculina subspherica d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 77.

This is the common species of the genus in the West Indian region. D'Orbigny originally described it from shore sands of Cuba and Jamaica. I found it common at Jamaica and at the Tortugas. It occurs in considerable numbers in San Juan Harbor at stations 1, 2, 4, 6, and 7.

Biloculina denticulata H. B. Brady.

Biloculina denticulata H. B. Brady, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 78.

Specimens occurred at stations 2 and 8. It also occurs in Jamaica and the Tortugas, and is a characteristic species of shallow-water, coral-reef conditions in the Indo-Pacific.

Peneroplis pertusus (Forskål).

Peneroplis pertusus (Forskål), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 78.

This is the least common of the West Indian species. It was rare both at Jamaica and the Tortugas. A few specimens occurred at station 6.

Peneroplis proteus d'Orbigny.

Peneroplis proteus d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 79.

As in other parts of the West Indies, this is the dominant species of the genus, occurring at stations 6, 7, and 8.

Monalysidium polita Chapman?

Monalysidium polita Chapman?, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 80, pl. 13, fig. 4.

The only other West Indian material is from the Tortugas, the remaining records for the species being Indo-Pacific. There is a single incomplete specimen from station 7.

Orbiculina compressa d'Orbigny.

Orbiculina compressa d'Orbigny, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 81.

This is somewhat less common at Porto Rico than the following species, *O. adunca*, but is one of the most abundant species of the collections, occurring at stations 4, 6, 7, 8, and 9. It was described by d'Orbigny from Cuba, Guadeloupe, St. Thomas, and Jamaica. I have had it from Jamaica and the Tortugas, at both places abundant, and from the Miocene Bowden marl of Jamaica.

Orbiculina adunca (Fichtel and Moll).

Orbiculina adunca (Fichtel and Moll), Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 81.

This is the most common species in the shallow-water collections from Porto Rico, stations 6, 7, and 8, in quiet water, being largely made up of the tests. It is common throughout the West Indian region.

Orbitolites duplex Carpenter.

Orbitolites duplex Carpenter, Cushman, Carnegie Inst. Wash. Pub. 311, 1922, p. 81.

Single, poor specimens may be referred to this species. It is the common species of the genus in the West Indian region, growing in great numbers attached to the short eel grass, *Posidonia*, in shallow water.

Mostly Rotalia beccarii (Linnaeus) var. tepida, new variety, with a few specimens of Polystomella poeyana d'Orbigny? ×0.9.

FOSSILS FROM QUARRIES NEAR SUVA, VITI LEVU, FIJI ISLANDS, AND FROM VAVAO, TONGA ISLANDS, WITH ANNOTATED BIBLIOGRAPHY OF THE GEOLOGY OF THE FIJI ISLANDS.

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With seven plates.

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FOSSILS FROM QUARRIES NEAR SUVA, VITI LEVU, FIJI ISLANDS, AND FROM VAVAO, TONGA ISLANDS, WITH ANNOTATED BIBLIOGRAPHY OF THE GEOLOGY OF THE FIJI ISLANDS.

By Wendell C. Mansfield.

FIJI ISLANDS.

COLLECTIONS STUDIED.

The collections here described consist of two lots of fossils from Viti Levu, Fiji Islands. The first lot received was collected by the U. S. F. C. *Albatross* in 1899, and subsequently deposited in the U. S. National Museum; the second lot was donated by Dr. Alfred G. Mayor to the museum during the year 1922. Photographs used for the illustrations of plates 1 and 2 were also furnished by Doctor Mayor.

Most of the specimens are poorly preserved, consisting, with few exceptions, of internal casts or external molds of shells. Because of the poor state of preservation of the specimens, specific characterization, and in some instances generic identification, is not practicable. Therefore it is not possible to ascertain with precision the relationship of these species to the living and extinct species that are identifiable. The difficulty of interpreting the small fossil fauna is also increased by the remoteness of the Fijis from areas in which the stratigraphic succession of faunas is known and by incomplete knowledge of the living faunas of the Tropical Pacific region.

The writer wishes to express his appreciation to the authorities of the U. S. National Museum for the use of the facilities of that institution and especially to Dr. T. Wayland Vaughan, under whose direction this work was undertaken, for his kind and helpful suggestions.

All stations are near Suva, Viti Levu, Fiji Islands, and are as follows:

4370. Quarry about a mile west of Suva; about 200 feet above sea-level. U. S. F. C. *Albatross*, collector, 1899.

1/132. Quarry east of hospital, north side of Walu Bay; altitude about 200 feet above sea-level. A. G. Mayor, collector, 1920.

1/131. Quarry at Walu Bay, above the soapstone; altitude about 200 feet. Coleman C. Wall, collector.

1/130. Quarry at Walu Bay; altitude 30 to 50 feet above sea-level. Coleman C. Wall, collector.

1/129. Quarry at Walu Bay; altitude not given. Coleman C. Wall, collector.

DESCRIPTION OF THE FAUNA.

MOLLUSCA.

Astræa sp.

(Plate 3, Figure 1.)

The species is represented by internal casts of two specimens, collected at station 4370, and appears referable to this genus. The specific characterization is wanting.

Figured specimen, U. S. N. M. Cat. No. 352427.

Turbo sp. a.

(Plate 3, Figure 2.)

The species is represented by internal casts of several specimens collected at station 4370. The shell possessed a moderately high spire and a large expanded last whorl. The ornamentation, if formerly present, has been corroded away.

Figured specimen, U. S. N. M. Cat. No. 352428.

Turbo sp. b.

(Plate 3, Figures 3*a* and 3*b*.)

The species collected at station 1/131, is represented by an incomplete external mold and an internal cast of the shell. The shell was prominently spirally sculptured both on the spire and base. The features are insufficiently characterized to definitely show its specific relationship.

Figured casts of specimen, U. S. N. M. Cat. No. 352430.

Trochus sp.

(Plate 3, Figures 4*a* and 4*b*.)

This species, collected at station 4370, is represented by four internal casts of the shell. The shell possessed a high spire and whorls deeply sulcated at the suture. The sculpture as faintly indicated consisted of moderately wide, rounded spiral bands.

Figured specimen, U. S. N. M. Cat. No. 352431.

Arca (Scapharca) sp. a.

(Plate 3, Figures 5*a*, 5*b*, and 5*c*.)

This species is represented by an internal cast of a single specimen with attached valves, and an external mold of the posterior end of the same specimen showing the sculpture. The umbones and cardial area are concealed by matrix.

The shell is of medium size, subquadrate and oblique; disks depressed at the anterior third of length and expanded at the posterior angle. Beaks are situated at the anterior third of dorsal line and are low and apparently separated by a narrow cardinal area. Anterior end of valves moderately rounded and gently slope to the margin; posterior end steeply sloping; posterior ridge prominent and roundly angular. Dorsal margin apparently nearly straight; ventral margin broadly rounded; anterior margin narrowly rounded; posterior margin nearly straight. Sculpture consists of about 40 ribs (est.), each medially incised over the middle of the disk and increased by more incisions on the ribs over the posterior slope, forming four narrow, longitudinal, raised bands on each rib.

The specimen (U. S. N. M. Cat. No. 352413) measures: length, 48 mm.; height, 40 mm.; greatest thickness, 27 mm.

Locality: 1/132. Altitude about 200 feet above sea-level.

The specimen above described is apparently related to *A.* (*Scapharca*) *sedanensis* Martin,[1] which is referred to "Altmiozän (nur Rembangsch)." Both possess similar sculpture, prominent posterior ridges, and anteriorly depressed disks.

Arca (Scapharca) sp. b.

(Plate 4, Figures 1*a* and 1*b*.)

This species is represented by an internal cast of attached valves with a part of the shell still preserved and adherent to the cast.

The shell is of medium size, elongate and subrhomboidal. Beaks are moderately high, separated by a wide, concave cardinal area, and situated near the anterior extremity of the shell. Anterior end of shell short and well rounded over the shoulder; posterior end elongate and gently sloping to margin and rounding over the shoulder. Hinge margin straight; ventral margin slightly diverging and widening from the hinge line in advancing posteriorly. The sculpture consists of moderately wide ribs, separated by narrower interspaces, the exact number of ribs indeterminable, probably about 30. As the shell is corroded and the extremities partially broken away, a fuller description is not practicable. The specimen (U. S. N. M. Cat. No. 352414) measures: length, 47 mm.; height, 33 mm.; greatest thickness, 27 mm.

Locality: 1/132. Altitude about 200 feet above sea-level.

Pecten (Chlamys) suvaënsis Mansfield, n. sp.

(Plate 4, Figures 2*a* and 2*b*.)

The shell is of medium size, orbicular, solid, equilateral, moderately inflated over the disk, and slightly compressed medially at and near the beak. The disk is radially sculptured by 18 low-keeled, nearly rounded ribs with interspaces of about half their width, in which there is a low, medial thread, becoming more prominent on nearing the margin; submargins about 3 mm. wide, without radial ribs; whole surface of shell ornamented with close-set, thread-like, concentric sculpture, becoming crowded and imbricated near and at the margins. Ears nearly equal, anterior ear slightly broken away at the byssal area, radially marked with low ribs, the anterior with 5, the posterior with 4, all over-run by fine, close-set imbrications. Type, right valve (U. S. N. M. Cat. No. 352415) measures: length, 50 mm., est. (25 mm. from posterior margin to middle between 9th and 10th ribs); height, 45 mm.; thickness, 8 mm.

Type locality: 1/132. About 200 feet above sea-level.

A fragment from station 4370 belongs to the same species and possibly is from the same quarry as the type.

The new species here described is related to *P. leopardus* Reeve.[2] In comparison with Reeve's figure, the ribs are found to be more diverging and without a medial keel, the interspaces wider and lacking the interradial thread, than in the new species.

K. Martin[3] identified forms with *P. leopardus* Reeve and gave its geological range.[4] "Miozän u. vermutlich pliozän; rezent."

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[1] Die Fossilien von Java, Samml. Geolog. Reichs-Mus. Leiden, N. F. Band 1, 2te Abtlg. Heft. 2, pp. 381-2, Taf. LIV, figs. 125-127, 1910.

[2] Reeve. Conch. Iconica, vol. VIII. Monogr. of the genus Pecten, pl. XXXII, fig. 145, 1853.

[3] Die tertiarschichten auf Java, Leiden, p. 123, Tab. 20, fig. 8, 1880.

[4] Unsere Palaezoologische Kenntnis von Java. Samml. Geolog. Reichs-Mus. Leiden, Beilage-Bd., p. 58, 1919.

Pecten (Chlamys) thomasi, n. sp.

(Plate 5, Figures 1*a* and 1*b*.)

Shell of medium size, oblique-ovate, solid, moderately inflated over the middle of the disk and compressed forward at the umbonal area. Hinge line short. Ribs 15 in number, low-keeled above and only slightly below, becoming more rounded distally; ribs separated by interspaces of about one-half their width. Radially sculptured over the whole surface of the disk and submargins by fine lines, being stronger over the ribs than interspaces; concentrically sculptured by close-set, minute, nearly erect, imbricated lamellae. Anterior ear small, marked by 3 to 4 fine, minutely crenulated radials within the byssal area and 3 stronger ones in front of it; posterior ear terminally broken off, but indicates similar markings to that of the anterior. Within, the resilium pit is triangular and large, on either side of which there are two other pits, the approximate ones marginate the ligamental area and the distal ones enter it.

The type is founded upon one left valve. Dimensions: length, 42 mm.; height, 45 mm.

Type locality, Walu Bay, Fiji Islands. Collected by A. O. Thomas.

The external sculpture of *Pecten thomasi* somewhat resembles that of *Pecten radula* (Linné), while the hinge articulation resembles more closely that of *Pecten plica* Linné.

The species is named in honor of Dr. A. O. Thomas, Professor of Paleontology, State University of Iowa, Iowa City, Iowa.

Lithophaga sp.

(Plate 5, Figures 2*a* and 2*b*.)

There are from station 4370 several internal casts of shells and burrows which are too poorly preserved for specific identification.

Figured specimen, U. S. N. M. Cat. No. 352433.

Chama sp.

(Plate 5, Figures 3*a* and 3*b*.)

The genus is represented by three internal casts. Only fragments of the original shell remain. The cast indicates a large, subquadrate, nearly equivalved shell. The beaks are prominent and strongly inflated—the left more so than the right and slightly more protruding. Posterior side is slightly depressed just below posterior shoulder; the anterior side is fuller. Posterior margin broadly rounded, except for a slight incurving at the depression on the posterior side; basal margin nearly straight, slightly incurved medially. Sculpture apparently consists of strong, concentric lamellae.

A specimen, station 4370 (U. S. N. M. Cat. No. 352417) measures: length, 49 mm.; height, right valve, 49 mm., left valve, 54 mm.; thickness of both valves, 35 mm.

Cardium sp.

(Plate 5, Figure 4.)

The specimens representing this genus consist of indeterminable internal casts. The shell was large and elongate-ovate; its anterior side rounded, posterior side steeply sloping and flattening out marginally; ribs more than 25.

A single valve from station 1/131 (U. S. N. M. Cat. No. 352418) measures: length, 67 mm.; height, 92 mm.; thickness, 26 mm.

Localities: Station 1/131, altitude about 200 feet; station 4370, altitude about 200 feet above sea-level; station 1/129, altitude not given; (?) station 1/132, altitude 200 feet.

Laevicardium sp.

(Plate 6, Figure 1.)

The genus is represented by internal casts of the shell. These casts show a high, subovate, inequilateral shell. The anterior end is oblique, produced and nearly straight, the posterior end rounded. The sculpture consists of many narrow, close-set radials.

A specimen at station 1/132 (U. S. N. M. Cat. No. 352419) measures: length, 35 mm.; height, 55 mm.; thickness (one valve), 15 mm.

Localities: 1/132, altitude 200 feet above sea-level; 1/129, altitude not given; (?) 4370, altitude 200 feet above sea-level.

Dosinia? sp.

(Plate 6, Figure 2.)

The species is represented by casts of single valves on which only faint indications of the sculpture are preserved. The shell was moderately high and semiorbicular. The anterior end and the middle part of the disk are inflated and evenly rounded; posterior end slightly depressed. The sculpture that is preserved consists of fine, concentric lamellae.

A single specimen at station 4370 (U. S. N. M. Cat. No. 352420) measures: length, 45 mm.; height, 40 mm.; thickness, 15 mm. Another specimen at station 1/129 measures: length, 55 m.; height, 50 mm.; thickness, 18 mm.

Localities: Station 4370, altitude about 200 feet; station 1/129, altitude not given; (?) station 1/131, altitude about 200 feet.

Meiocardia? sp.

(Plate 6, Figures 3*a* and 3*b*.)

This questionable genus, collected at station 4370, is represented by an internal cast of the umbonal part of the original shell. The cast is nearly flat over its middle area, strongly ridged from the beak distally at the dorsal-posterior angle, and concave behind this ridge. The sculpture, as faintly indicated, consisted of concentric markings.

Figured specimen: U. S. N. M. Cat. No. 352435.

Antigona sp. a.

(Plate 6, Figures 4.)

The species is represented by an internal cast of a single valve; fragments of the shell remain and adhere to the cast. The valve is suborbicular, very inequilateral; disk inflated over the anterior and middle areas, and slightly depressed below the shoulder on the posterior slope. Dorsal margin is elongate and nearly rectilinear and oblique; anterior, ventral, and posterior margins broadly rounded. The sculpture, where intact, consists of concentric lamellae, apparently rather widely spaced, and fine, low radials with interspaces about twice their width. A single valve from station 1/129 (U. S. N. M. Cat. No. 352421) measures: length, 40 mm.; height, 39 mm.; thickness, 12 mm.

Locality: Station 1/129. Altitude not given, but the matrix is the same as that at the quarry at altitude of 200 feet.

The shape and the sculpture appear similar to that of a Recent species "*Cytheria*" *lacerata* Hanley collected at Tongatabu, one of the southernmost of the Tonga Islands.

Antigona sp. b.

(Plate 6, Figure 5.)

The species is represented by a poorly preserved single right valve, which is broken away over the middle of the disk and at the margins. The shell is of

medium size and suborbicular in form, strongly arched over the posterior angle and slightly depressed below, near the dorsal and posterior margins. Anterior end rounded over the shoulder and side. The sculpture consists of erect, concentric lamellae and rather coarse radials.

The species at station 1/129 (U. S. N. M. Cat. No. 352422) measures: length, 62 mm.; height, 54 mm.; thickness, 30 mm.

Locality: Station 1/129, altitude not given.

A fragment from station 1/130, from an altitude of 30 to 50 feet, may belong to the same form.

The forms from Suva belong to the group of *Venus listeri* Gray. K. Martin[1] gives the geologic range of this species: "Altmiozän (nur West-Progogeb); rezent."

Tellina suvaënsis Mansfield, n. sp.

(Plate 6, Figure 6*a* and 6*b*.)

This species is represented by an internal cast of attached valves and a cast of an external mold of its right valve.

The shell is large, subovate, nearly equilateral, and posteriorly laterally flexuous. Right valve inflated at anterior end and slopes at low angle to margins; posterior end with two narrow, prominent, diverging radial ridges separated by a shallow sulcus, the anterior one more prominent and forms the ridge of the posterior shoulder; marginal posterior area steeply sloping. Left valve less inflated anteriorly than right, medially inflated over region opposite to depression on right valve. Sculpture consists of microscopic radials and many close-set, erect, concentric lamellae.

Type from station 1/132 (U. S. N. M. Cat. No. 352423) measures (cast of external mold), length, 48 mm.; height, 32 mm.; (internal cast), length, 43 mm.; height, 33 mm.; thickness, 11 mm.

Locality: Station 1/132. Altitude about 200 feet.

The new species closely resembles *T. plicata* Valenc.,[2] described and figured by Reeve,[3] but the radials on the posterior side are less diverging and separated by a shallower sulcus than those on *T. plicata* Valenc. K. Martin[4] gives the geological range of *T. plicata* Valenc.: "Jungmiozän (nur Tjilanangsch.); rezent."

Asaphis sp.

(Plate 7, Figure 1.)

The species is represented by a single left valve which is somewhat crushed and corroded. The shell is moderately high, inequilateral, and slightly medially inflated. Anterior end is rounded at the shoulder; posterior end more angled and elongate. Sculpture consists of about 100 fine, close-set radials; the ornamentation on the anterior and posterior slopes indicate a more scabrous and cancellated structure.

The specimen from station 1/129 (U. S. N. M. Cat. No. 352424) measures: length, 52 mm.; height, 33 mm.; thickness, 13 mm.

Locality: Station 1/129. Altitude not given, but may be about 200 feet.

The species is similar to *Asaphis deflorata* Linné, a Recent species.

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[1] Unsere Palaeozoologische Kenntnis von Java. Samml. Geolog. Reichs-Mus. Leiden. Beilage-Bd., p. 64, 1919.

[2] Enc. Meth., pl. 287, fig. 3, 1798.

[3] Conch. Icon., vol. 17, Tellina, pl. 26, fig. 142, 1867.

[4] Unsere Palaeozoologische Kenntnis von Java. Samml. Geolog. Reichs-Mus. Leiden, Beilage-Bd., 1919, p. 68.

PISCES.

Carcharodon megalodon Agassiz.

(Plate 7, Figures 2*a* and 2*b*.)

Carcharias megalodon Agassiz, Poiss. Foss. Tome III (Atlas), Tab. 29, 1835.

Carcharias megalodon Agassiz, Charlesworth. Notice of the teeth of *Carcharias megalodon* occurring in the Red Crag of Suffolk. Mag. Nat. History, new ser., vol. 1, p. 225, text fig., 1837.

Carcharodon megalodon (Agassiz) Agassiz. Poiss. Foss., pp. 247, 248, 249, 1843. (Description.)

Among the citations to the literature on *Carcharodon megalodon* references are made by O. P. Hay,[1] by Frederick Chapman,[2] and by Y. Ishiwara.[3]

The measurements of the shark's tooth collected from the quarry at Walu Bay, station 1/129, altitude not given (U. S. N. M. Cat. No. 352425) are: height of crown on outer surface, 57 mm.; width of crown at base, 20 mm.; thickness of root, 25 mm. Number of serrations on anterior side, 130 (tip of the tooth broken off).

List of Fossils from Suva, Viti Levu.

	Sta. 4370. Alt. 200.	Sta. 1/132. Alt. 200.	Sta. 1/131 alt. 200. Above soapstone.	Sta. 1/130 Alt. 30-50.	Sta. 1/129. Alt. not given.
Mollusks:					
Astraea sp	×				
Turbo sp. *a*	×				
Turbo sp. *b*			×		
Trochus sp	×				
Arca (Scapharca) sp. *a*., aff. A. sedanensis Mart		×			
Arca (Scapharca) sp. *b*		×			
Pecten (Chlamys) suvaënsis, n. sp., aff. P. leopardus Reeve	×	×			
Pecten (Chlamys) thomasi, n. sp					×
Lithophaga sp	×				
Chama sp	×				
Cardium sp	×	(?)	×		×
Laevicardium sp	(?)	×			×
Dosinia? sp	×		(?)		×
Meiocardia? sp	×				
Antigona sp. *a*., aff. "Cytheria" lacerata Hanley					×
Antigona sp. *b*., aff. "Venus" listeri Gray				(?)	×
Tellina suvaënsis n. sp., aff. T. plicata Valenc		×			
Asaphis sp.,? aff. A. deflorata Linné					×
Pisces:					
Carcharadon megalodon Agassiz					×

[1] Bibliography and catalogue of the fossil vertebrata of North America. U. S. Geol. Survey Bull. 179, p. 308, 1902.

[2] Descriptions and revisions of the Cretaceous and Tertiary fish-remains of New Zealand. N. Z. Geol. Survey, Palæont. Bull. 7, p. 19, 1918.

[3] On some fossil shark-teeth from the Neogene of Japan. Sci. Rept. Tôhoku Imperial Univ., second ser. (Geology), vol. 5, No. 3, p. 65, 1921.

In regard to the geological range of *C. megalodon*, F. Chapman[1] gives its occurrence in New Zealand: "Cape Foulwind, Westport, Nelson; Weka Pass; Boby's Creek, near Waipara," and gives its age, "Tertiary (Eocene to Miocene)." On page 19, idem, the same author gives its range in Victoria, "Oligocene to Lower Pliocene." K. Martin[2] refers this species to "jungmiozän." Y. Ishiwara[3] assigns this species from Japan to the Miocene.

In Europe *Carcharodon megalodon* has been assigned both to the Miocene and Pliocene. In eastern United States it is known only from the Miocene.

Professor T. W. Edgeworth David,[4] in a letter, reported the occurrence of large teeth of *Carcharodon* at rifle butts, Walu Bay, and W. G. Woolnough[5] figured a large *Carcharodon* tooth taken from an upraised reef at Walu Bay.

AGE OF THE FAUNA FROM THE QUARRIES NEAR SUVA.

In the literature examined I find, with one or two exceptions, only generic determinations of the larger organisms such as mollusks, corals, and vertebrates collected from the quarries near Suva.

Different interpretations of the age of the so-called "soapstone," with its intercalated coral-bearing limestones, especially well exposed in the cliffs near Suva, have been made by several writers. The different views of the age assignments may be found in the annotated bibliography prepared for this paper.

The collections described in this paper do not indicate any faunal distinctions at the different altitudes if there should be such distinctions.

The fauna suggests a Tertiary age, probably late Miocene or early Pliocene.

The forms that suggest a Miocene age are: An *Arca*, designated *A.* (*Scapharca*) sp. *a.* which apparently is related to *A.* (*Scapharca*) *sedanensis* Martin,[6] a species reported by the same author[7] "Altmiozän;" and *Carcharodon megalodon* Agassiz, which species in nearly all instances has been reported from the Miocene.

Aside from the above, the following forms are the better preserved specimens: *Pecten* (*Chlamys*) *suvaënsis* n. sp., which species is related to *P. leopardus* Reeve, a species assigned to the "Miozän u. vermutlich pliozän; rezent" by Martin;[8] *Tellina suvaënsis*, n. sp., a form related to *T. plicata* Valenc., and assigned to "Jungmiozän

[1] Descriptions and revisions of the Cretaceous and Tertiary fish-remains of New Zealand. N. Z. Geol. Survey, Palaeont. Bull. No. 7, p. 20, 1918.

[2] Unsere Palæozoologische Kenntnis von Java. Samml. Geolog. Reichs-Mus. Leiden. Beilage-Bd., p. 105, 1919.

[3] On some fossil shark-teeth from the Neogene of Japan. Sci. Rept. Tôhoku Imperial Univ., 2d ser. (Geology), vol. 5, No. 3, p. 66, 1921.

[4] Harvard Coll. Mus. Comp. Zool. Bull. 38, p. 7, 1900.

[5] Linn. Soc. N. S. W. Proc., vol. 28, pl. 23, fig. 3, 1903.

[6] K. Martin. Die Fossilien von Java. Samml. Geolog. Reichs.-Mus. Leiden, N. F. Band 1, 2te Abtlg., Heft 2, pp. 381, 382, Taf. LIV, figs. 125-127, 1910.

[7] K. Martin. Unsere Palaeozoologische Kenntnis von Java. Samml. Geolog. Reichs-Mus. Leiden Beilage-Bd, 1919, p. 60.

[8] Unsere Palaeozoologische Kenntnis von Java. Samml. Geolog. Reichs-Mus. Leiden, Beilage-Bd., 1919, p. 58.

(nur Tjilanangsch); rezent" by Martin;[1] *Antigona* sp. *a.*, aff. "*Cytheria*" *lacerata* Hanley, a recent species; *Antigona* sp. *b.* aff. "*Venus*" *listeri* Gray, a species assigned to "Altmiozän (nur West-Progogeb); rezent," by Martin;[2] and *Asaphis* sp. aff. *A. deflorata* Linné, a recent species. Concerning the other forms little may be said.

TONGA ISLANDS.

On May 8, 1920, Dr. A. G. Mayor obtained a small collection of fossils from Vavao, Tonga Islands, in a road-cut near the summit of the lowermost of three terraces at an elevation of about 100 feet. The following mollusks were obtained:

Cypraea sp.
Tridacna gigas Linné (see pl. 7, fig. 3), U. S. N. M. Cat. No. 352426.
Codakia sp. (frag.) aff. *C. interrupta* Lam., a recent species from Tonga Islands.

From this small collection it is hardly possible to determine the geologic horizon; however, the fauna suggests a post-Tertiary age rather than earlier.

None of the forms listed appear to be in my list from Fiji. However, I note that Professor T. W. E. David reports in a letter[3] the genus *Tridacna* taken from rifle butts at Walu Bay quarry. Martin[4] gives the geological range of *Tridacna gigas* Linné "Altmiozän; jungmiozän (Tjilanangsch); rezent."

ANNOTATED BIBLIOGRAPHY OF THE GEOLOGY OF THE FIJI ISLANDS.

Agassiz, Alexander. The Tertiary elevated limestone reefs of Fiji. Amer. Jour. Sci., vol. 6, 4th ser., pp. 165–167, 1898.

The author states on p. 165, first paragraph: "Dr. William H. Dall has been kind enough to examine the fossil mollusks which I collected from the elevated limestone reefs in Fiji. He confirms the impression I had formed of their late Tertiary age."

———. The Fiji Islands and coral reefs. Harvard College Mus. Comp. Zool. Bull., vol. 33, pp. 167, 44 text-figs., 112 plates, 1899.

The author, in referring to the age of "The Tertiary elevated limestones of Fiji," on p. 71, writes: "While elevated coralliferous limestones of late Tertiary age occur along the shores of Viti Levu evidently of the same age as the limestones of Lau, yet there is evidence of the existence of older rocks as a nucleus of the larger Fiji Islands." On pp. 71–72, he writes: "The existence of the Tertiary elevated coralliferous limestone at so many points in the Fiji Archipelago (plate 2) seems to indicate a huge limestone bed of great thickness and extent, formed during Tertiary times, along the flanks of ancient volcanic islands, and elevated by subsequent intermittent volcanic action during more recent times over areas of varying dimensions, . . . "

[1] Loc. cit., p. 68.
[2] Loc. cit., p. 64.
[3] Harvard College Mus. Comp. Zoöl. Bull., vol. 38, p. 7, 1900.
[4] Unsere Palaeozoologische Kenntnis von Java. Samml. Geolog. Reichs-Mus. Leiden, Beilage-Bd., p. 62, 1919.

AGASSIZ, ALEXANDER—*Continued.* The coral reefs of the tropical Pacific. Harvard Coll. Mus. Comp. Zool. Mem., vol. 28, XXXIII+410 pp., 238 pls., 1903.

The Fiji Islands are considered and questions relating to the geology are treated in a general way.

ANDREWS, E. C. Notes on the limestones and general geology of the Fiji Islands, with special reference to the Lau Group. Based upon surveys made for Alexander Agassiz, with a preface containing a letter written by T. W. Edgeworth David (pp. 5–11) and an introductory note by Alexander Agassiz (pp. 3–4). Harvard Coll. Mus. Comp. Zool. Bull., vol. 38, pp. 1–50, 39 plates, 1900.

In this report the stratigraphic succession of the formations of Fiji, with a description of each formation, is given.

On p. 7, the Fiji "soapstones" are placed, in ascending order, at the top of the third series of formations in Fiji.

On p. 7, Professor David states: "I observed a large clam-shell (*Tridacna*) at the rifle butts at Walu Bay Quarry, and was shown large teeth of *Carcharodon* from this quarry by Sir Henry Barclay. Mr. Andrews has forwarded you a similar *Carcharodon* tooth. The evidence of these fossil sharks' teeth alone would prove the formation to be at least as old as Pliocene, while the occurrence of *Tridacna* shows that it is referable to the later rather than to the earlier Tertiaries."

On p. 44, Andrews writes: "On the west side of Suva harbor beds occur that pass gradually from soapstone to a sandy limestone rock. There is no sharp line of demarcation. The one shades insensibly into the other. Exteriorly it often presents a rough and hard appearance, but breaks down under the hammer into a sandy clay rock. At various times large serrated *Carcharodon* teeth, carapaces and plastra of turtles have been unearthed from the Suva stone. The rock is rarely cavernous and contains few fossils."

ANDREWS, E. C. Relations of coral reefs to crust movements in the Fiji Islands. Amer. Jour. Sci., 4th ser., vol. 41, pp. 135–141, 1916.

In regard to the island of Viti Levu, on p. 138, he writes: "The present Great Barrier Reef, which rises to the level of the sea, has thus, in all probability, been built up by coral-reef organisms upon the submerged lowlands of Viti Levu."

BARTSCH, PAUL. Mollusca determined by. Amer. Acad. Arts and Sci. Proc., vol. 54, p. 86, 1918.

Cardium sp.?, Walu Bay, Suva, Viti Levu (30–50 feet).
Cypraea sp.?, Walu Bay, Suva, Viti Levu (24 feet).
Lithophagus sp.?, Walu Bay, Suva, Viti Levu (25 feet).
Lithophagus sp.?, Na Sana Sana, S. W. Viti Levu (10–15 feet).
Lucina sp.?, Mbuambua, west of the mouth of the Singatoka River (10–15 feet).
Pecten sp.?, Na Sana Sana, S. W. Viti Levu (10–15 feet).
Pecten sp.?, Mbuambua, Singatoka district (10–15 feet).
Tapes sp.?, Na Sana Sana, S. W. Viti Levu (10–15 feet).
Trochus sp.?, Na Sana Sana, S. W. Viti Levu (10–15 feet).
Trochus sp.?, Mbuambua, S. W. Viti Levu (10–15 feet).
Trochus sp.?, Walu Bay, Suva, Viti Levu (25 feet).
Turritella sp.?, Na Sana Sana, S. W. Viti Levu (10–15 feet).
Venus sp.?, Na Sana Sana, S. W. Viti Levu (10–15 feet).
Venus sp.?, Mbuambua, S. W. Viti Levu (10–15 feet).
Venus sp.?, Walu Bay, Suva, Viti Levu (25 feet).

BRADY, H. B. Note on the so-called "soapstone" of Fiji. Geol. Soc. London Quart. Jour., vol. 44, pp. 1–10, 1 pl., 1888.

On p. 3 the author writes, in referring to the Suva deposit: "Its chemical composition varies within certain limits, but may be roughly stated as about 50 per cent silica; 18 per cent alumina; 5 or 6 per cent lime and magnesia; a variable quantity (from 3 to 8 per cent) ferric oxide; and 16 per cent water; with a small proportion of alkalies, chiefly potash."

On pp. 7 and 8 he also states: "Turning now to the question of geological age, there need not, I think, be the slightest hesitation in assuming the Post-tertiary origin of the deposits under consideration. Of the ninety-two species of Foraminifera which have been identified, eighty-seven are forms still living in the neighborhood of the Pacific Islands; whilst the remaining five, two of which are new to science, are all extremely rare, and from one cause or other may easily have been overlooked hitherto in the examination of recent dredgings."

The material examined was collected at Suva at cutting on the shore road, near sea-level; at an elevation of 100 feet or more; and from an intermediate point.

BROCK, R. W. Sketch of the geology of Vitu Levu, Great Fiji. Roy. Soc. Canada Trans., vol. 18, 3d ser., sec. 4, pp. 63–83, 1924.

The author, under the heading "General geology" (page 66), has constructed a "Table of formations." In this, the age of the Suva formation is referred to the Pleistocene or late Pliocene. This formation apparently includes all the material exposed in the quarries near Suva.

COCHRANE, N. D. Rocks of Fiji. Legislative Council Paper, No. 15, Suva, Fiji, 1911.

A report on "samples of the most prominent rocks— * * " of Viti Levu and Vanua Levu, briefly describing "all the principal minerals contained in these sections and which, *on grouping, give each rock* its *character* and *name*."

Only a few rocks are described from Vanua Levu.

On p. 16, the author writes: "The mudstones are locally known as 'soapstones' from their fine, slippery character, but at times the material has been coarser, when the beds become more of the nature of sandstones. These strata have been mostly derived from the volcanic rocks, more especially from the ash, and at times no doubt, they and the tuffs are the equivalent of each other at the submarine and landward positions of the same bed. They form extensive and usually only slightly inclined strata, along most of the coastal plains and extend at low levels, as far inland in the incised channels of the rivers, as Serea on the Rewa and Waisa on the Sigatoka Rivers. At times their continuity on the shore-line, as on the Tailevu coast, is interrupted by volcanic flows, which then frequently form bold headlands. Inland from Suva—Colo-i-Suva—they occur many hundred feet above sea-level; at Nakoroboya and Nadarivatu in the north, at about 2,000 feet, and at high levels between these districts, clearly proving a great elevation of the land during Tertiary time."

DALL, W. H. Letter to Agassiz as quoted by Agassiz. Amer. Jour. Sci., vol. 6, 4th ser., p. 165, 1898.

"The fossils comprise *Turbo, Cassis, Lithophaga, Macha, Tellina, Meretrix, Dosinia, Chama, Pholas,* and fragments of *Pecten.* None of the genera are extinct. The rock, however, looks decidedly too old for Pleistocene. I should say the fossils were younger than Eocene and might be either Miocene or Pliocene."

DALY, R. A. Igneous rocks and their origin. 1914.

An alkaline eruptive rock from Fiji is included in "Table XXIII," p. 525.

DALY, R. A.—*Continued.* The glacial-control theory of coral reefs. Amer. Acad. Arts and Sci., vol. 51, pp. 157–251, 1915.

References are made to the Fiji Islands.

DANA, J. D. Report of the United States exploring expedition (Wilkes), vol. 10, Geology, pp. 337–352, 1849.

The geological features and structure of the "Viti Islands" are described in a general way.

———. Coral reefs and islands. Pages 143, 2 maps, 1853.

On p. 131, the author, in discussing the changes of level of the "Feejee Islands," writes: "The proofs of an elevation of four to six feet about the larger Feejee Islands, Viti Lebu and Vanua Lebu, and also Ovalau, are given in our report on this group."

———. Corals and coral islands. 398 pp., 8°, 1872.

The author in discussing the "Period of the subsidence" in the Pacific coral regions, on p. 331, states: "The period during which these changes were in progress, extends back to the Tertiary era, and perhaps still farther back."

On p. 327, in referring to the subsidence of the Fiji Islands, he states: "The subsidence, where least, could hardly have been less than 2,000 to 3,000 feet."

On p. 332, the author in discussing "Elevations of Modern Eras in the Pacific," states: "Since the period of subsidence discussed in the preceding pages, there has been no equally general elevation. Yet various parts of the ocean bear evidence of changes confined to particular islands, or groups of islands."

———. Manual of Geology. 2 ed., 1875.

The author in discussing "System in the courses of the earth's feature-lines" writes, on p. 34: "The large Feejee group lies near the intersection of the three Pacific chains; and hence its numerous islands do not conform to either one, though the larger islands approximate most nearly to the last in direction."

DAVIS, W. M. The home study of coral reefs. Amer. Geog. Soc. Bull. vol. 46, pp. 561–577, 641–654, 721–739, 1914.

Contains, especially, explanations and applications of the theories pertaining to the formation of oceanic coral reefs. References are made to the elevated coral reefs of Fiji.

———. A Shaler memorial study of coral reefs. Amer. Jour. Sci., vol. 40, pp. 223–271, 1915.

On pp. 249 and 250, the author, in discussing the "Elevated reefs in the Fiji group" and referring in particular to the "soapstone" with intercalated elevated reefs at Walu Bay, writes: "The soapstone beds of the emerged delta were nowhere seen in contact with their foundation; but a few miles east of Suva a creek, that has cut a valley across them, disclosed in its rapids a little distance inland from the soapstone area and a few feet above present sea-level, a ledge of volcanic boulders and cobbles, water-worn and well cemented; it was therefore concluded that when these cobbles were rounded the island was standing at least as high as now; that a submergence of a few hundred feet then permitted the deposit of the delta beds, in which the intercalated reefs mark short-lived periods of local coral growth, prevented earlier and later by excess of muddy sediments, but allowed for a time while the delta-forming river mouthed some distance away; and that emergence placed the delta, with its little local reefs, in an elevated position. Since then, mature valleys have been eroded in the high-standing delta; . . . "

DAVIS, W. M.—*Continued.* The islands and coral reefs of Fiji. Geog. Jour., vol. 55, pp. 34–45, 200–220, 377–388, 1920.

On p. 212, the author writes: "This aspect of the coral-reef problem has a geological flavour and therefore will not be treated at length here; but it should be said that, excepting the small elevated reef at Walu Bay, Suva, which lies conformably between inclined delta-like beds of volcanic muds containing marine fossils and locally known as "soapstone," all the other elevated reefs as well as practically all the sea-level fringing reefs of Fiji lie in unconformable contact on foundation surfaces of subaerial erosion." . . . "It may be noted in passing that the above-mentioned "soapstones" are the uplifted marine beds which Guppy regarded as contradicting the supposed subsidence of Viti Levu; but in reality they seem to give evidence of two periods of subsidence; for as well as I could make out their structural relations they lie unconformably on an eroded slope of older volcanic rocks, and they are without question overlaid unconformably by the younger sea-level reef-limestones of the southern coast. The island must have long ago stood higher than now while its volcanic slope was eroded; it must have subsided to a lower level than now while the soapstones were deposited; it must have risen to a higher level than now while the soapstones were suffering erosion; and it must then have been moderately submerged in order to give the soapstones their present embayed shoreline and to permit the formation of their unconformable reef border."

EAKLE, A. S. Petrographical notes on some rocks from Fiji Islands. Amer. Acad Arts and Sci. Proc., vol. 34, pp. 581–595, 1899.

On p. 582 the author writes: "Viti Levu, besides being the largest and most important island of the group, possesses much more geological interest than the rest of the islands, since it is essentially different in its rock formations. Wichman has shown that granites, syenites, diorites, and gabbros occur on this island, as well as crystalline schists and limestones; and he reaches the conclusion that the island was an old continental mass composed of these older plutonic rocks which stood above the water during the whole of the Paleozoic and Mesozoic ages. During the Tertiary the island was submerged, and received its stratified deposits of limestone, sandstone, and conglomerate, and was also rent by volcanoes."

FORBES, H. O. Antarctica: A vanished austral land. Fortnightly Review, new ser., vol. 55, No. 326, pp. 194–214, 1894.

On p. 199 the author writes: "In the May number of the Fortnightly Review [new ser., vol. 53, p. 686, 1893] I have already drawn attention to the fact that what now constitutes New Zealand was but a small portion of a once far greater continental island—which I have designated Antipodea—stretching south as far at least as the Macquarie Islands, and embracing all those lying between them and the Chatham Islands, as well as those to the northward as far as New Caledonia, the Fiji, the Friendly, and the Kermadec islands . . . "

FOYE, W. G. Geological observations in Fiji. Amer. Acad. Arts and Sci. Proc., vol. 54, pp. 1–145, 1918.

On p. 9, the author writes: "The larger islands of Viti Levu and Vanua Levu have central cores of deeply eroded plutonic rocks and are thought to be remnants of an older continental mass."

"There have been four periods of vulcanism in Fiji . . . "

"There are two series of sedimentary rocks in Viti Levu. The folded series of the interior resemble the folded series of the New Hebrides, which Mawson believes to be Miocene. The coastal-plain series have low dips and, by fossil evidence, are apparently post-Tertiary in date."

On p. 87, the author writes: "It is believed, therefore, that the older folded series of central Viti Levu are the equivalents of Mawson's Miocene folded series

of the New Hebrides. The formation of the coastal-plain series of Viti Levu would then be referred to late Pliocene or Pleistocene time. . . ."

"The ages of the plutonic rocks of central Viti Levu and of the sediments which they intrude can only be conjectured. The erosion which exposed these rocks was completed before the Miocene depression. They are doubtless at least as old as the early Tertiary."

GARDINER, J. S. The coral reefs of Funafuti, Rotuma, and Fiji, together with some notes on the structure and formation of coral reefs in general. Camb. Phil. Soc. Proc., vol. 9, pp. 417–503, 1898.

On p. 452, under the heading, "The raised reefs of Fiji," the author discusses the raised reefs at and near Suva. The stratigraphic sequence, relation, and lithologic character and origin of the beds are given in detail.

GERLAND, G. Beiträge zur Geophysik, vol. 2, p. 56, 1895.

Not seen.

GRAEFFE, EDWARD. Reisen im Innern der Insel Viti-Levu. Pages 48, 1 pl., 1 map.

See Zurich. Naturforschende Gesellschaft, Neujahrsblatt, Stück LXX, 1868.

GUPPY, H. B. Observations of a naturalist in the Pacific, vol. 1, 392 pp., 5 pls., 2 lithos., 20 figs., London, 1903.

Contains a description of the leading physical and geographical characters of Vanua Levu. Several references are made to Viti Levu.

HEDLEY, CHARLES. A zoogeographic scheme for the Mid-Pacific. Linn. Soc. N. S. Wales Proc., vol. 24, pp. 391–417, 1899.

On p. 401, in referring to a former publication ("Hedley-Linn. Soc. N. S. W. (2) [series], VI [vol.], 1892, p. 336"), the author writes in part: "Yet the Samoas possess a distinctive oceanic molluscan fauna comparable to that of Tahiti, while the molluscan fauna of the Fijis is as distinctly continental."

HORNE, J. A year in Fiji, or an inquiry into the botanical, agricultural, and economic resources of the colony. Pages 297, with map, 1881.

Not seen.

JENSEN, H. I. Note on copper in andesite near Lautoka, Fiji. Royal Soc. N. S. W. Jour. and Proc., vol. 41, pp. 49–55, 1907.

JHERING, H. VON. On the ancient relations between New Zealand and South America. N. Z. Inst. Trans. and Proc., vol. 24, pp. 431–445. (Read Aug. 6, 1891), 1892.

References are made to the Fiji Islands.

JONES, T. R., and W. K. PARKER. On the Foraminifera of the family Rotalinae (Carpenter) found in the Cretaceous formations; with notes on their Tertiary and Recent representatives. Geol. Soc. London Quart. Jour., vol. 28, pp. 103–131, 1872.

Among the lists there is, on pp. 124–125, a corrected list of recent Foraminifera "found by Mr. G. D. MacDonald among the Fiji Islands. See Ann. Nat. Hist., ser. 2, vol. XX, pp. 193, etc., 1857."

KLEINSCHMIDT, TH. Reisen auf den Viti-Inseln. Mus. Godeffroy Jour., vol. 5, pl. 14, pp. 249–283, 1879.

Not seen.

MARSHALL, P. Oceania. Handb. region. Geol. vol. 7, pt. 2, 36 pp., 10 figs., 1911.

The nature and geologic succession of the rocks of Viti Levu are given on p. 20.

The "so-called soapstone" is referred to the "Cainozoic age." A brief summary of the geological history of Viti Levu taken from W. G. Woolnough's publication, "A contribution to the geology of Viti Levu," is given.

MURRAY, SIR JOHN. On the structure and origin of coral reefs and islands (abstract). Royal Soc. Edinburgh Proc., vol. 10, pp. 505–518, 1880.

PARKER, W. K. (See JONES, T. R., and PARKER, W. K.).

RENARD, A. Report on the petrology of oceanic islands, physics and chemistry. Voyage of H. M. S. *Challenger*, vol. 2, pt. 7, pp. 180, 7 maps, 1889.

Deals principally with petrography.

SAWYER, B., and E. C. ANDREWS. Notes on the caves of Fiji, with special reference to Lau. Linn. Soc. N. S. W. Proc., vol. 26, pp. 91–106, 1901.

Interesting features as to the location, nature, origin, kind of rocks, etc., of the caves are described.

SHERLOCK, R. L. The foraminifera and other organisms in the raised reefs of Fiji. Harvard Coll. Mus. Comp. Zoöl. Bull., vol. 38, pp. 349–365, 1903.

The author writes, on pp. 349–350: "The Tertiary age of certain of the rocks has been proved in two cases by the discovery of *Orbitoides*, and in one of these cases the rock is shown by the specific characters of the organism to be Miocene."

The author writes in the first paragraph, p. 349: "The rocks described were obtained from various islands in the Pacific Ocean, but chiefly from the Fiji and Tonga Groups."

SKEATS, E. W. The chemical composition of limestones from upraised coral islands, with notes on their microscopical structures. Harvard Coll. Mus. Comp. Zoöl. Bull., vol. 42, pp. 53–126, 1903.

On p. 120, the author writes: "With regard to the rocks of the raised limestones of the Fijis, Tongas, etc., Mr. Agassiz maintains (Bull. Mus. Comp. Zoöl., 1899, vol. 33, p. 10) that they consist mainly of Tertiary masses of limestone, an opinion largely based on their altered appearance and their relation to the undoubtedly more modern fringing reefs and terraces which occur on some of their slopes. I am able to confirm this opinion by fossil evidence from two of the islands of the Fiji group. In Mango a form of *Orbitoides* occurs at a level of 310 feet, which Mr. Frederick Chapman kindly identified for me as *Orbitoides* [*Lepidocyclina*] *sumatrensis*, a Miocene form from Christmas Island, Sumatra, and Borneo. The rock in which it occurs is, therefore, presumably of Miocene age."

"One of the limestones from Namuka, another of the Fiji group, also contains a form of undoubted *Orbitoides*, which was, however, not capable of being specifically identified."

SUESS, E. Das Antlitz der Erde. (French translation by E. de Margerie; English translation by Hertha B. C. Sallas); 3 vols. and index, 3,695 pp., 5 pls., 10 maps, 551 figs., 1905–1918.

On pages 356, 357, 358 (Dritter Band, Zweite Halfte, 1909), the leading geological investigators of the Fiji Islands, with a brief summary of their results, are given.

On p. 317 (vol. 4, English translation, 1909,) reads: "In the south-west of the island we come upon older limestone (according to Andrews, dolomite also); it is hard, bluish-yellow in colour, and dips at an angle of 50°. Woolnough compares it with pebbles obtained from Guadalcanar and Ysabel. It is overlain by a thick regularly stratified limestone containing shells, which dips at an angle of 15°. This limestone reappears as the substructure of the great atoll of Vanua Mbalavu in the Lau islands. It is, no doubt, the same as that which Dall regarded as middle or upper Tertiary."[1]

"Still more recent is the limestone of the south-east coast containing great teeth of Carcharodon; it occurs alternately with beds of tuff."

TENISON-WOODS, J. E. On some fossils from Levuka, Viti. Linn. Soc. N. S. W. Proc., vol. 4, pp. 358–359, 1879.

A collection of fossils from the center of the island, exact locality unknown, was examined. The determined corals comprise *Fungia* (genus not quite certain), *Flabellum*, and "A cast or the internal septa, with a small portion of the wall of a doubtful coral not unlike one of the genus *Conosmilia*, of Duncan." The mollusks comprise, *Conus*, *Oliva*, *Natica*, *Turritella* (2 sp.), *Trophon*, *Turbonilla* (cast), *Corbula*. Some of the specific affinities of the genera are given.

The age, on p. 358 is given ". . . probably tertiary, and possibly belonging to an early formation of that period."

VAUGHAN, T. W. Sketch of the geologic history of the Florida coral-reef tract and comparisons with other coral-reef areas. Jour. Wash. Acad. Sci., vol. 4, pp. 26–34, 1914.

The author states, on p. 33: "A study of the charts of the barrier reef islands, as Viti Levu, Fijis, and Tahiti, Society Island, shows that the platforms are independent of the presence of reefs, and therefore the relations in these islands are similar to those indicated for barriers off continental shores, for here the reefs are also superimposed on platforms antedating their presence."

———. The platforms of barrier coral reefs. Amer. Geograph. Soc. Bull., vol. 46, pp. 426–429, 1914.

Discusses Fijian reefs on p. 428.

———. The present status of the investigation of the origin of barrier coral reefs. [A preface to "Relations of coral reefs to crust movement in the Fiji Islands," by E. C. Andrews.] Amer. Jour. Sci., 4th ser., vol. 41, pp. 131–135, 1916.

———. List of determined corals collected from the Lau Group and from the elevated reef at Suva. Amer. Acad. Arts and Sci. Proc., vol. 54, p. 85, 1918.

Age assigned, "Pleistocene or Recent."

[1] A. Agassiz, Tertiary elevated limestone reefs of Fiji. Amer. Jour. Sci., 1898, 4th ser., vol. v, pp. 165-167.

VAUGHAN, T. W.—*Continued.* Fossil corals from Central America, Cuba, and Porto Rico, with an account of the American Tertiary, Pleistocene, and Recent Coral Reefs. U. S. Nat. Mus. Bull. 103, pp. 189–507, 1919.

The author, on p. 311, states: "The information bearing on the Fijis may be summarized as follows:

"1. The fringing reefs have unconformable basal contacts, as do those of the West Indies.

"2. The barrier reefs are superposed on antecedent platforms of diverse origin during or after submergence.

"3. The submergence is concomitant with, if not actually due to, differential crustal movement.

"4. In that they were formed during or after submergence and are superposed on antecedent platforms, the offshore reefs of the Fijis accord with all others, perhaps except a Barbadian reef, so far considered."

———. Notes on Tertiary deposits in Sumatra, Nias, Borneo, Celebes, Timor, and Oceania. 1st Pan Pacific Sci. Conference Proc., pt. 3, pp. 766–69, 1921.

The author writes, on p. 769, under the heading "Oceania": "I have found on the paleontology of Oceania virtually no literature on which correlations might be based although fossiliferous deposits of probably Tertiary age have been reported from several localities, the Solomon[1] and Fiji[2] islands for instance, but the fossils, mostly foraminifera, have not been critically studied. . . ."

———. Studies of fossils from Walu Bay, Fiji; etc. Carnegie Inst. Wash. Year Book No. 21, pp. 187–188, 1923.

The author writes, on page 187: "The presence of teeth of the shark *Charcharodon megalodon* Agassiz, as well as the fossil mollusks, in the quarries at Walu Bay, Vitu Levu, indicates that the rocks there exposed are probably of late Miocene, possibly Pliocene, age."

WICHMANN, A. Beitr. z. Petrographie d. Viti-Archipels. Tschermak, Min, Mitth., vol. v, pp. 2–66, 1833.

Not seen.

WOOLNOUGH, W. G. The continental origin of Fiji. Linn. Soc. N. S. W. Proc., vol. 28, pp. 457–496 and 500–540, 14 plates, 1903.

The author writes, on pp. 463 and 464, under the heading "The Geological Sections:" "About one mile north of Suva, on a branch of the harbour known as Walu Bay, there is an interesting and instructive section (plate 22, figs. 1–2). From the bank of the creek there is a long steep slope of talus leading up to the face of a cliff. The lowest exposure in the cliff consists of a well marked bed of conglomerate containing large, perfectly rounded pebbles of a great variety of rocks. . . . At all events, we have distinct evidence of a considerable landmass existing at the time the conglomerate was formed. Overlying the conglomerate is an upraised reef with corals *in situ*. This has yielded a considerable number of fossils of various kinds, the assemblage of which appears to indicate that the bed is not newer than Pliocene. Conspicuous amongst these fossils are the teeth of a large *Carcharodon* (pl. 23, fig. 3)."

On plate 34, a stratigraphic section of the raised coral reef interstratified with "soapstone" at Walu Bay, near Suva is given. The coral reef here is described as follows: "Yellowish grey coral-reef rock formed chiefly of corals, *lithothamnion* and *foraminifera*, with *Turbo marmoratus, Chama, Cardium, Lithodomus*, large *Tridacna* and teeth of *Carcharodon*."

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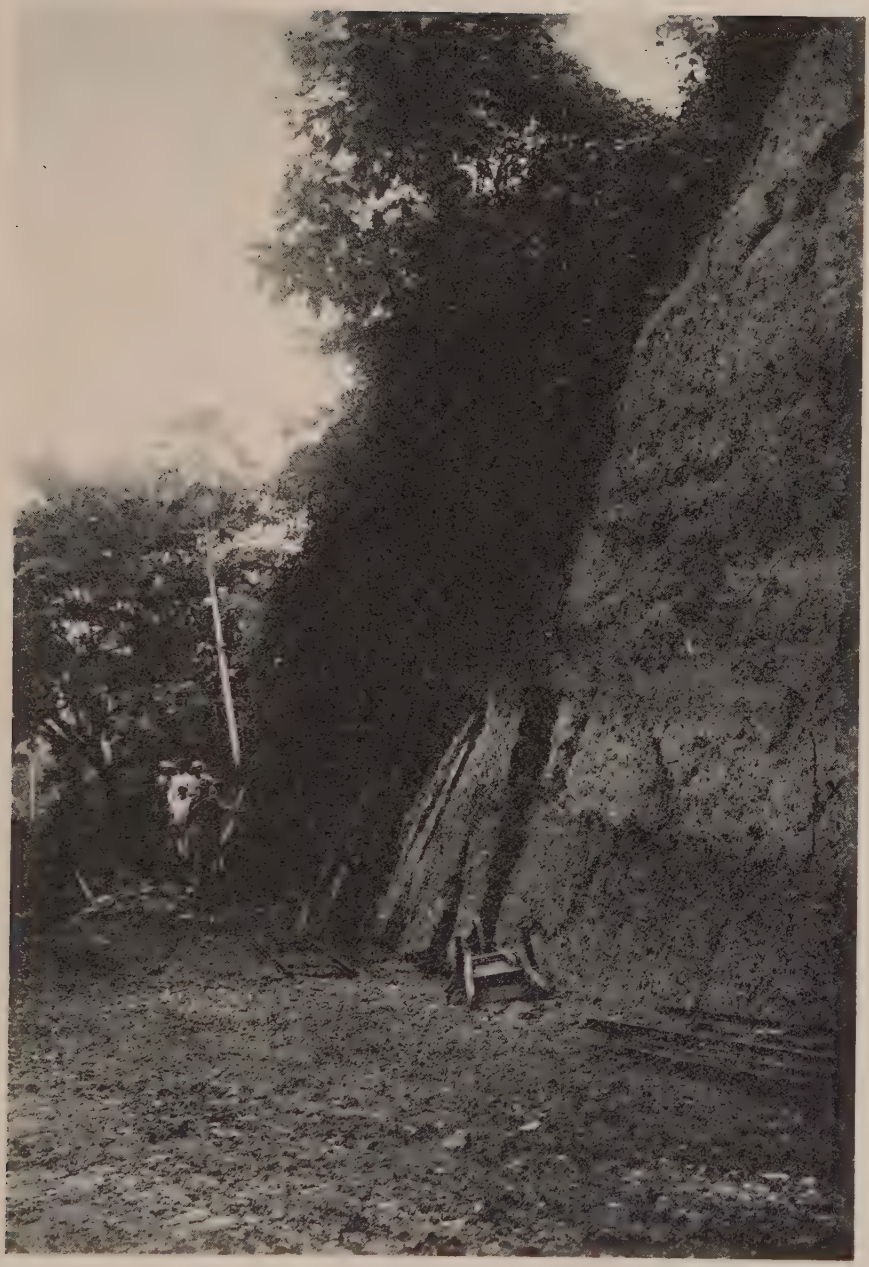
[1] E. C. Andrews. Notes on the limestones and general geology of the Fiji Islands with special reference to the Lau Group. Harv. Coll. Mus. Comp. Bull., vol. 38, pp. 1-50, 40 pls., 4 text figs., 1900. Marshall, op. cit., p. 20.

[2] P. Marshall. Oceania. Handb. region. geol., vol. 2, pt. 2, p. 17, 1911.

WOOLNOUGH, W. G.—*Continued.* A contribution to the geology of Viti Levu, Fiji. Linn. Soc. N. S. W. Proc., vol. 32, pp. 431–474, 5 pls., 1907.

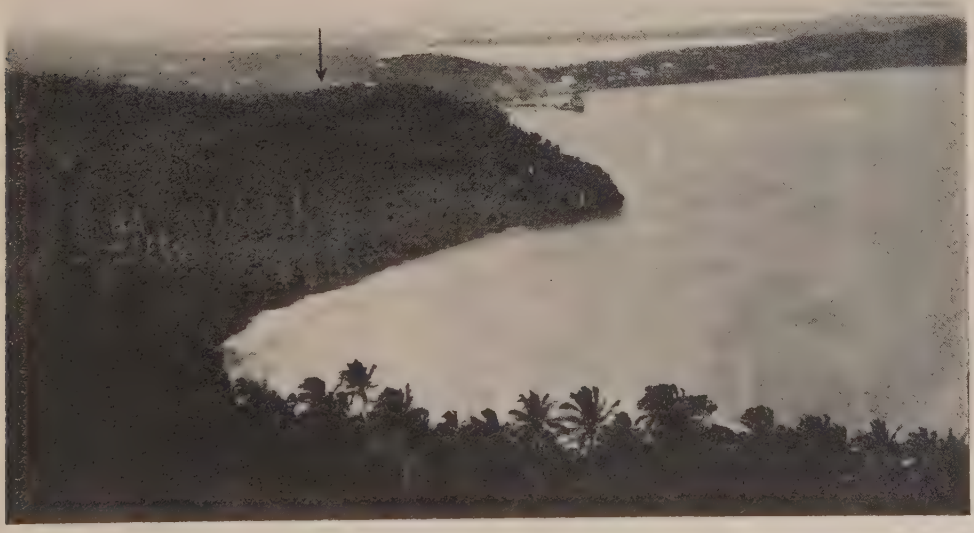
On p. 436, the author states: "Fossiliferous limestones of middle Tertiary age were met with at Walu Bay, Suva, and at Tawaleka, Sigatoka River. An immense mass of dense white limestone occurs at Naqalimare, on the Sigatoka, but has yielded no fossils."

On p. 472, the author, after citing evidence, states: " . . ., all lead towards the conclusion that Viti Levu, and therefore probably the whole of Fiji, has been a land-area for enormous periods of time, even reckoned geologically . . . "

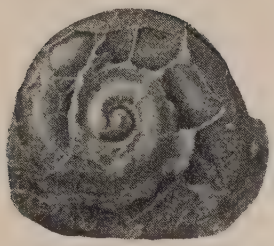


Quarry back of Hospital, near Suva, Viti Levu, Fiji. Cross on right side of picture indicates position of fossiliferous limestone (about 200 feet above sea-level) overlain and underlain by "soapstone."

A. Vavao, Tonga Islands. Arrow points to second terrace. The fossils were from this terrace.



B. Vavao, Tonga Islands. Arrow points to where fossils were found.



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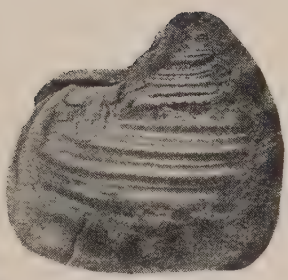
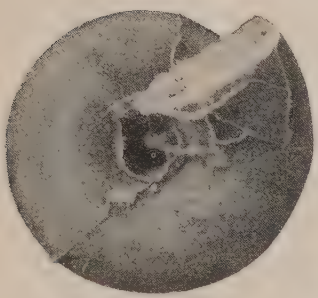
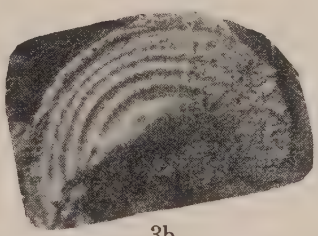


3a



4a

4b



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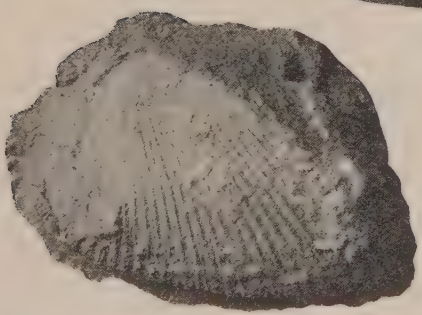
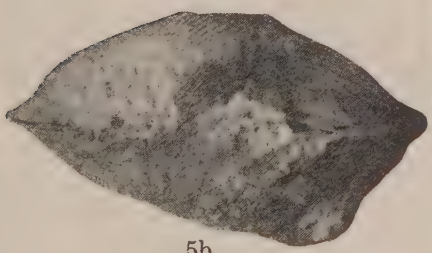


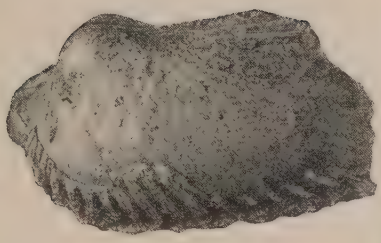
5a



5b

5c

1. Astraea sp. Apical view of internal cast. ×2. See p. 88.
2. Turbo sp. *a*. Apertural view of internal cast. ×2. See p. 88.
3a. Turbo sp. *b*. Impression of spire from external mold. ×2. See p. 88.
3b. Turpo sp. *b*. Impression of base from external mold. ×2. See p. 88.
4a. Trochus sp. Basal view of internal cast. ×2. See p. 88.
4b. Trochus sp. Apertural view of above specimen. ×2. See p. 88.
5a. Arca (Scapharca) sp. *a*. Left valve. ×1. See p. 88.
5b. Arca (Scapharca) sp. *a*. Dorsal view of above specimen. ×1. See p. 88.
5c. Arca (Scapharca) sp. *a*. Sculpture of ribs over posterior slope of same specimen. ×4. See p. 88.



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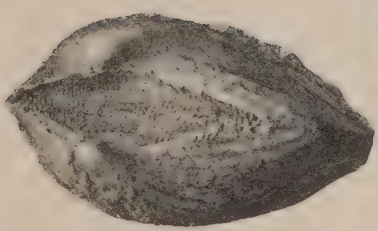
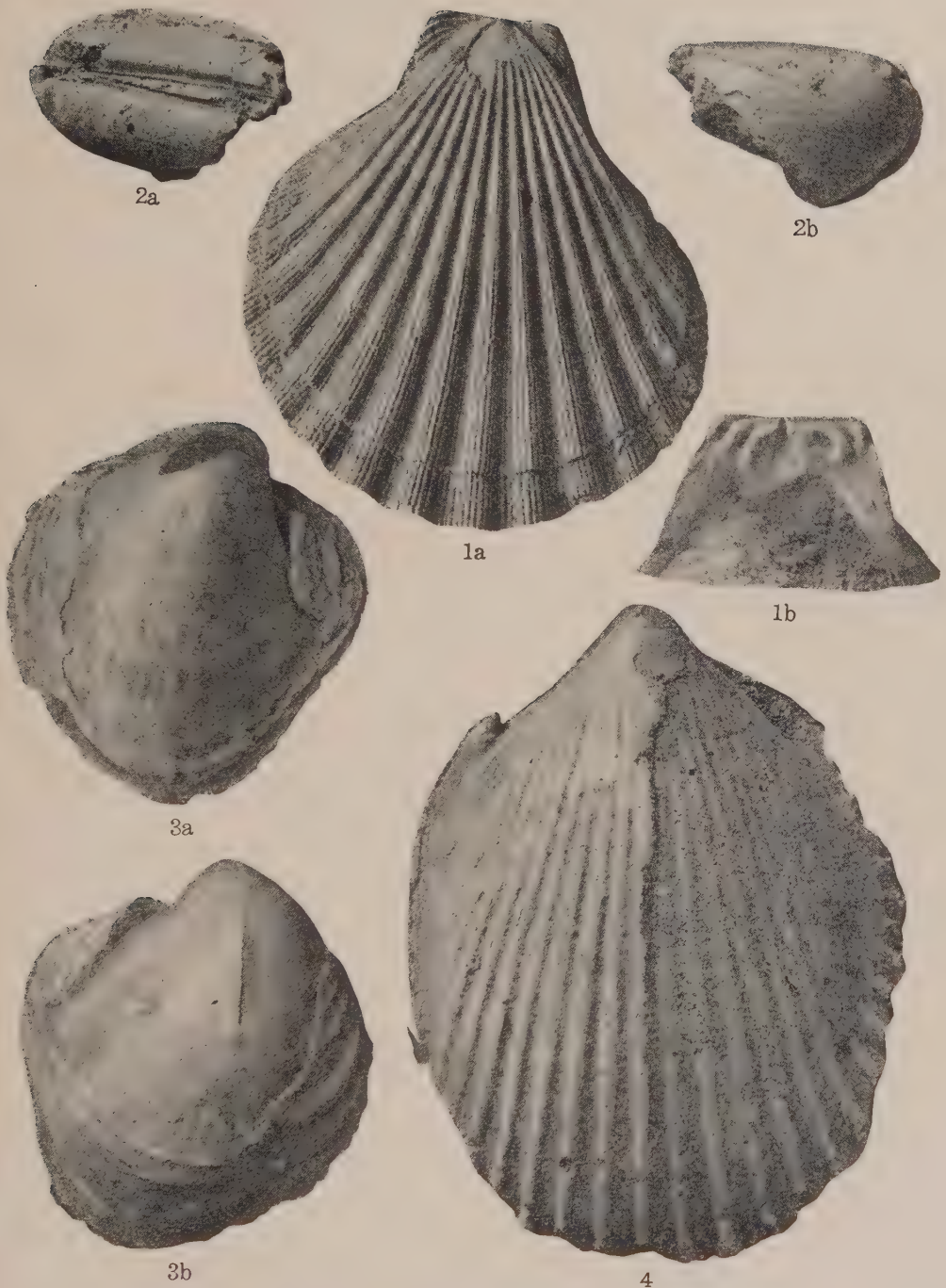


1b

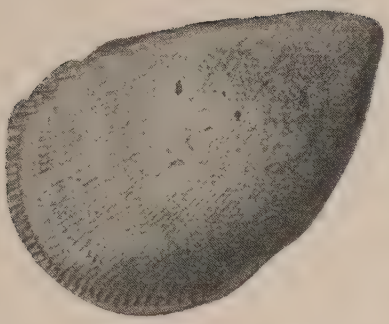
2b

2a

1a. Arca (Scapharca) sp. *b*. Left valve. ×1. See p. 89.
1b. Arca (Scapharca) sp. *b*. Dorsal view of above specimen. ×1. See p. 89.
2a. Pecten (Chlamys) suvaënsis n. sp. Type. Right valve. ×1. See p. 89.
2b. External sculpture of type near center of disk. ×4. See p. 89.
3. Pecten (Chlamys) suvaënsis, n. sp. External sculpture. ×4, of a fragment from Station 4370, about 1 mile west of Suva. See p. 89.



1a. Pecten (Chlamys) thomasi, n. sp. Type. Left valve. ×1½. See p. 90.
1b. Pecten (Chlamys) thomasi, n. sp. Interior of above specimen. ×2, showing hinge articulation. See p. 90.
2a. Lithopaga sp. Dorsal view of an internal cast. ×1½. See p. 90.
2b. Lithopaga sp. Side view of above specimen. ×1½. See p. 90.
3a and 3b. Chama sp. Views of same specimen. ×1. See p. 90.
4. Cardium sp. ×1. See p. 90.



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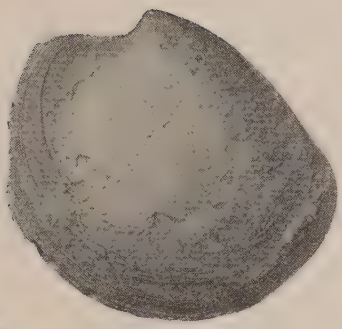

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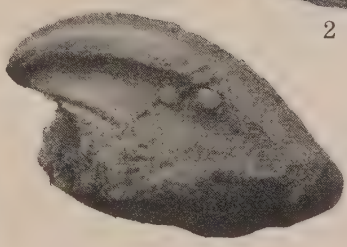
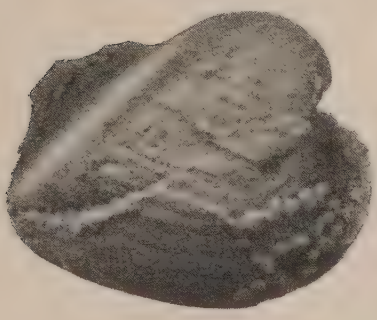
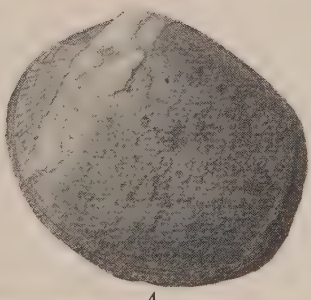


3b



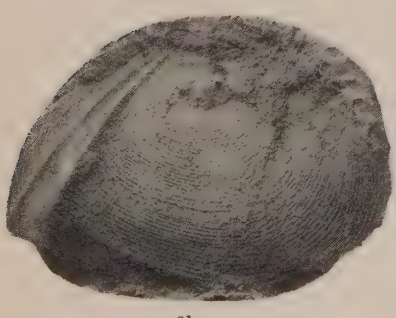
3a



4

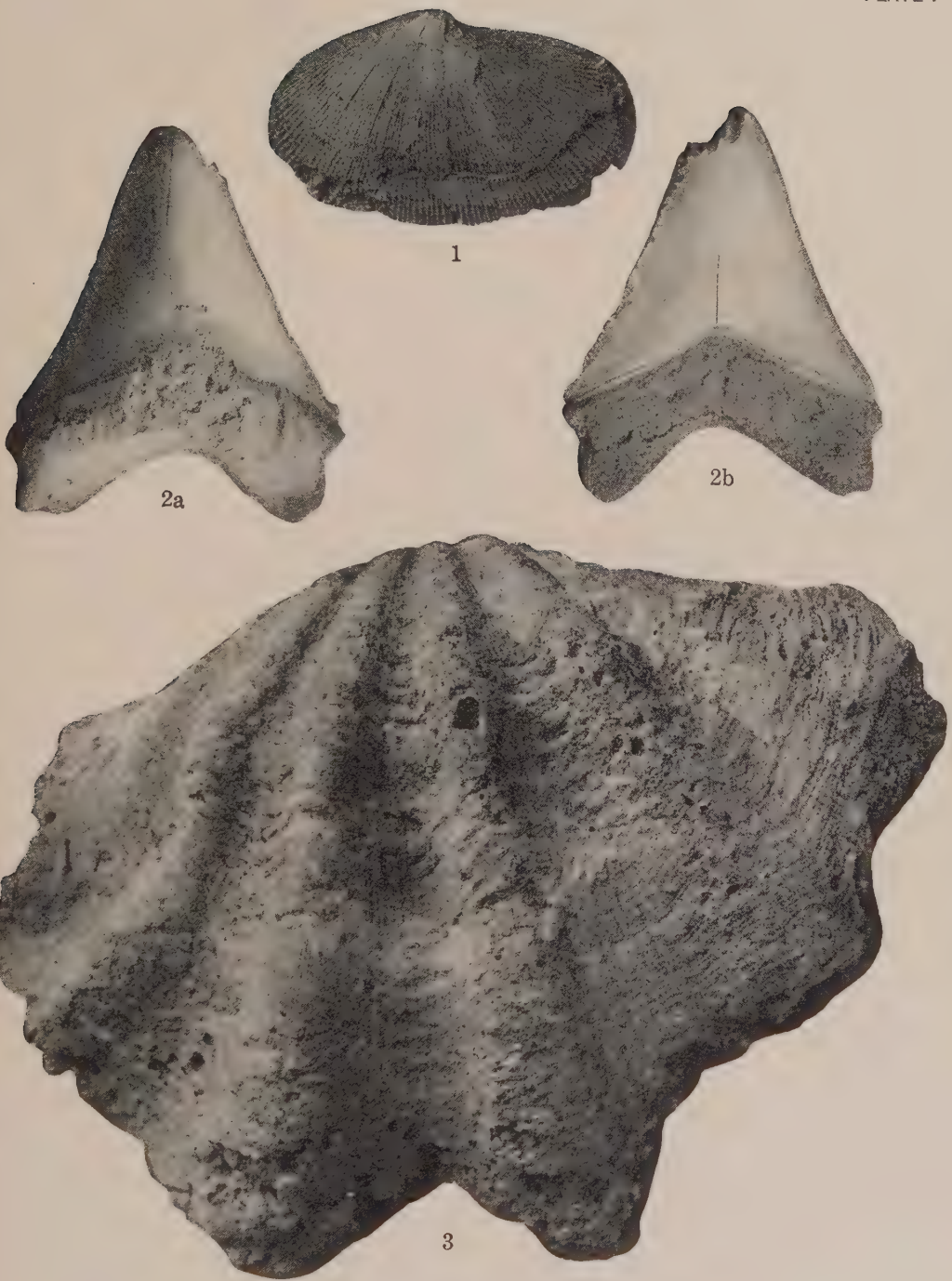
6a

5



6b

1. Lævicardium sp. ×1. See p. 91. 2. Dosinia? sp. ×1. See p. 91.
3a. Meiocardia? sp. Internal cast of fragment back of beak. ×2. See p. 91.
3b. Anterior side of above specimen. ×2. See p. 91.
4. Antigona sp. *a*. ×1. See p. 91. 5. Antigona sp. *b*. ×1. See p. 91.
6a. Tellina suvaënsis, n. sp. Type. Internal cast of left valve. ×1. See p. 92.
6b. Tellina suvaënsis, n. sp. Impression of external mold of right valve of above specimen. ×1. See p. 92.



1. Asaphis sp. ×1. See p. 92.
2a and 2b. Carcharodon megalodon Agassiz. Views of opposite sides of same specimen. ×1. See p. 93.
3. Tridacana gigas Linné. ×1. See p. 95.

MIOCENE CORALS FROM TRINIDAD.

By

Thomas Wayland Vaughan and John Edward Hoffmeister.

With seven plates and one text-figure.

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MIOCENE CORALS FROM TRINIDAD.

By Thomas Wayland Vaughan and John Edward Hoffmeister.

The fossil corals on which this paper is based were generously sent by Mr. F. W. Penny and Mr. J. A. Bullbrook of Pointe-à-Pierre, Trinidad. Those sent by Mr. Penny, which represent the greater part of the collection, were studied by the senior author. Mr. Bullbrook's collection was subsequently received and studied by the junior author, who has also assisted in writing the part on the geologic age of the coral faunas and has prepared the paper for publication.

DUNCAN'S WORK ON FOSSIL CORALS FROM TRINIDAD.

Prior to the present paper the only publication on the fossil corals of Trinidad is one by Duncan,[1] in which he records the following forms from St. Croix:

Heliastraea endothecata (Duncan).
cylindrica (Duncan).
**barbadensis* (Duncan).
cavernosa (Linnæus).
altissima Duncan, new species.
Brachyphyllia eckeli Duncan, new species.
irregularis Duncan, new species.
Astraea pariana Duncan, new species.
Isastraea confusa Duncan, new species.
**Stylophora raristella* (Defrance)
minuta Duncan, new species.
**mirabilis* Duchassaing and Michelotti.
Stephanocoenia intersepta (Esper).
Agaricia agaricites (Linnaeus).
**undata* (Ellis and Solander).
**Porites collegniana* Michelin.
astreoides Lamarck.
**Alveopora daedalea* (Forskål).

The six names preceded by an asterisk are almost certainly misapplied. Experience in checking Duncan's identification of West Indian corals with European species has been to find him invariably wrong, in some instances the West Indian and European species not even belonging to the same genus. *Heliastraea barbadensis* (Duncan), originally described from the Pleistocene reefs of Barbados, is a synonym of the Pleistocene and living *Orbicella annularis* (Ellis and Solander) of the Caribbean and Mexican Gulf region. *Stylo-*

[1]Duncan, P. M. On the fossil corals (Madreporia) of the West Indian Islands, Part IV: Geol. Soc. London Quart. Jour., vol. 24, pp. 10-14, with figures on pl. 2, 1867.

phora mirabilis Duchassaing and Michelotti is not a species of *Stylophora* but belongs to the genus *Madracis*. The specimens from Antigua identified by Duncan as *Alveopora daedalea* belong to the genus *Goniopora* and not to *Alveopora*. The types of two species described by Duncan (*Astraea pariana* and *Stylophora minuta*) disintegrated before figures of them had been made, and as the second of them is unidentifiable from the description it is, therefore, given no further consideration. This leaves 11 species to be considered. Duncan's *Astraea pariana* probably should be referred to the genus *Siderastrea;* and, judging from his figure, his *Isastraea confusa* certainly should be placed in that genus. Data for the identification of *Brachyphyllia* (type species *B. dormitzeri* Reuss from the Upper Cretaceous of Gosau) are inadequate. As good a revised list of the corals recorded by Duncan from St. Croix, Trinidad, as is at present practicable is as follows:

Stephanocoenia intersepta (Esper).
Orbicella cavernosa (Linnaeus).
var. *cylindrica* (Duncan).
var. *endothecata* (Duncan).
altissima (Duncan).
Brachyphyllia? eckeli Duncan.
? irregularis Duncan.
Agaricia agaricitis (Linnaeus).
Siderastrea pariana (Duncan).
confusa (Duncan).
Porites astreoides Lamarck.

STATIONS AT WHICH MATERIAL OF PRESENT PAPER WAS COLLECTED.

Mr. F. W. Penny and Mr. J. A. Bullbrook have sent collections of fossil corals from the following localities in Trinidad:

Gasparillo Quarry; lat. 10° 19′ 50″ N., long. 61° 25′ 10″ W.; U. S. G. S. station 8297.

Nariva Road Quarry; lat. 10° 23′ 40″ N., long. 61° 17′ 10″ W.; U. S. G. S. stations 8298 and 9198.

Cumuto Road, 17 mile; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; U. S. G. S. stations 8299 and 9217.

Machapoorie Quarry; lat. 10° 27′ 25″ N., long. 61° 14′ 35″ W.; U. S. G. S. stations 8301 and 9220.

Brasso, 1 mile south of railway station, lat. 10° 23′ 45″ N., long. 61° 19′ 18″ W.; U. S. G. S. station 8302. Specimens washed out of the flood-wash from a stream bank.

Rock, 1 mile south of twelfth mile on Rock-Penal Road; lat. 10° 7′ 25″ N., long. 61° 20′ 45″ W.; U. S. G. S. station 8303. Picked up in the bed of a streamlet.

Rock, 1.5 miles south of the ninth mile on Rock-Penal Road; lat. 10° 6′ 55″ N., long. 61° 22′ 10″ W.; U. S. G. S. station 8304. A specimen thrown up by an active volcano.

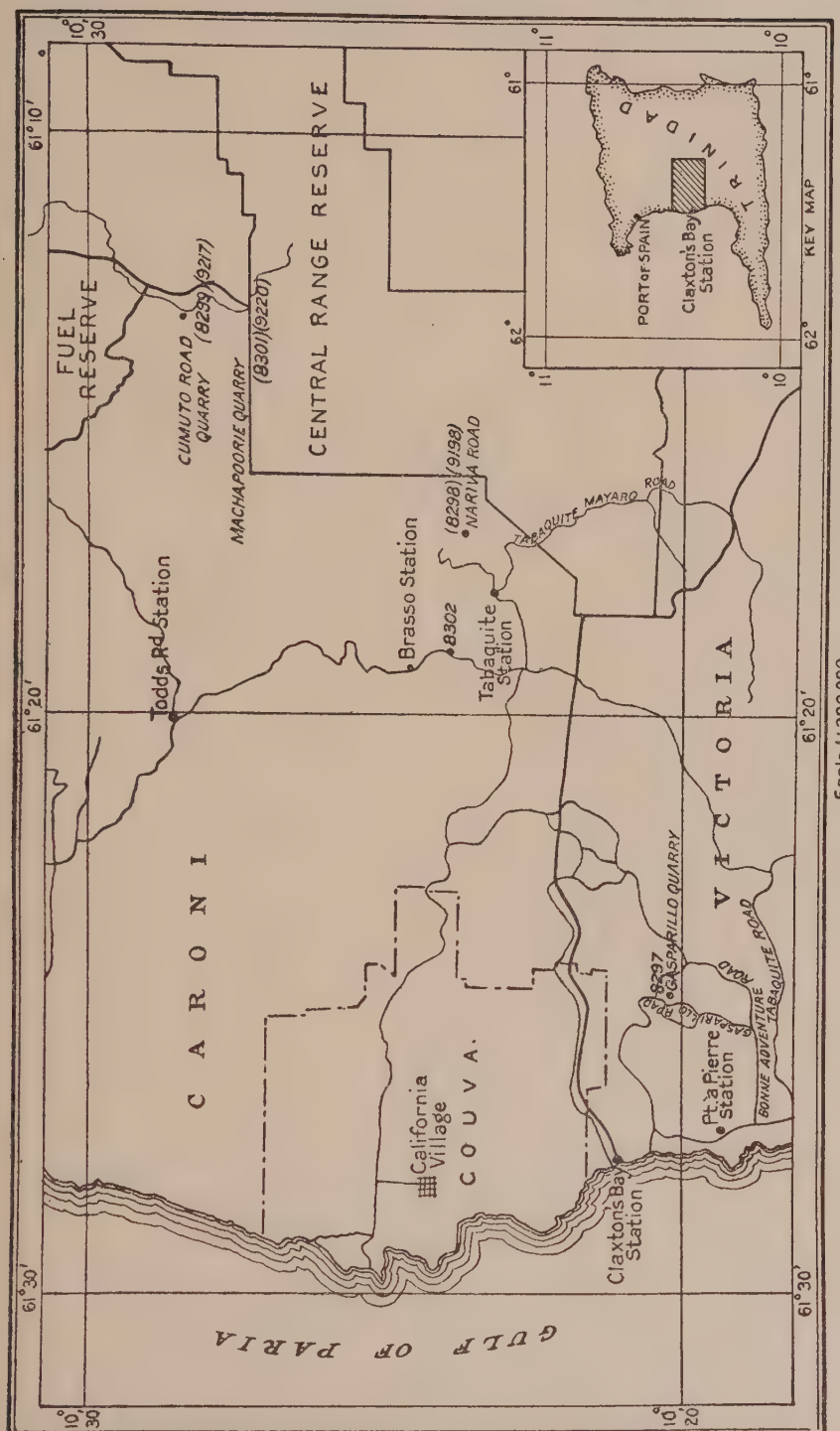


FIG. 1.—Map showing important localities from which corals were collected.

Quarry 0.25 mile down Hindustan Junction branch road, which runs south from mile 13½ on the San Fernando-Mayaro main road. From Amphistegina limestone. Station 9286.

The positions of the most important of these stations are shown on text-figure 1; and the names of corals collected at each station, with notes on the occurrence elsewhere, when the species has been found outside Trinidad, are given in table 1.

TABLE 1.—*Fossil corals from Trinidad.*

Name.	Station 8297	Station 8298	Station 8299	Station 8301	Station 8302	Station 8303	Station 8304	Station 9220	Station 9217	Station 9198	Station 9286	Occurrence outside Trinidad.
Sphenotrochus trinitatis Vaughan, n. sp	....	....	....	x	....	....	....	....	....	....	....	
brassensis Vaughan, n. sp	....	....	....	....	x	....	....	....	....	....	....	
Placocyathus trinitatis Vaughan, n. sp	....	....	....	x	....	....	....	....	....	....	....	
Stylophora imperatoris Vaughan	....	....	x	x	....	....	....	x	x	....	....	Canal Zone, Emperador limestone.
sp. indet	x	....	....	....	....	....	....	....	....	....	....	
Madracis sp. aff M. mirabilis (Duch. and Mich't).	....	....	....	....	x	....	....	....	....	....	....	Cuba, Costa Rica, Miocene.
Asterosmilia trinitatis Vaughan, n. sp	....	....	x	x	....	....	....	....	x	....	....	
machapooriensis Hoffmeister, n. sp	....	....	....	x	....	....	....	....	....	....	....	
Antillia sawkinsi Vaughan, n. sp	....	....	x	....	....	....	....	....	x	....	....	
bullbrooki Hoffmeister, n. sp	....	....	....	....	....	....	....	....	....	....	x	
Orbicella limbata var. pennyi Vaughan, n. var.	x	x	....	....	....	x	....	....	....	x	....	Dominican Repub., Miocene.
cumutensis Hoffmeister, n. sp	....	....	....	....	....	....	....	....	x	....	....	
altissima (Duncan)	x	....	....	....	....	....	....	....	....	....	....	Do.
trinitatis Vaughan, n. sp	....	....	x	....	....	....	....	....	....	....	....	Dominican Repub., (Baitoa formation).
cavernosa var. cylindrica (Duncan)	x	....	....	....	....	....	....	....	....	....	....	Dominican Repub., Miocene.
brevis (Duncan)	....	x	....	....	....	....	....	....	....	....	....	Do.
Goniastrea trinitatis Vaughan, n. sp	....	....	....	....	....	....	x	....	....	....	....	
Thysanus sp	....	....	....	....	x	....	....	....	....	....	....	
Mycetophyllia bullbrooki Vaughan, n. sp	....	....	x	....	....	....	....	....	....	....	....	
Pavona pennyi Vaughan, n. sp	....	....	x	....	....	....	....	....	....	....	....	
trinitatis Vaughan, n. sp	....	....	x	....	....	....	....	....	....	....	....	
machapooriensis Vaughan, n. sp	....	....	....	x	....	....	....	....	....	....	....	
Leptoseris walli Vaughan, n. sp	....	....	x	....	....	....	....	....	x	....	....	
Siderastrea siderea (Ell. and Sol.)	....	x	....	....	....	....	....	....	....	....	....	Dominican Repub., Cuba, Miocene.
Psammocora trinitatis Vaughan, n. sp	....	....	x	....	....	....	....	....	x	....	....	
gasparillensis Vaughan, n. sp	x	x	....	....	....	....	....	....	....	....	....	Baitoa formation, Dominican Repub. Thomonde formation, Haiti, Lower Miocene.
wyckoffi Hoffmeister, n. sp	....	....	....	....	....	....	....	....	....	....	x	
Porites aff. P. porites (Pallas)	....	....	x	....	....	....	....	....	....	....	....	
trinitatis Vaughan, n. sp	....	....	x	....	....	....	....	....	....	....	....	
aff. P. astreoides Lamarck	x	x	x	....	....	....	....	....	....	....	x	Cuba, Dominican Repub., Miocene.

GEOLOGIC AGE OF THE CORAL FAUNAS.

Comparisons with the known faunas of other areas bring to light geologic age relations of more of the localities than is revealed by the above table. The faunas, beginning with the oldest, will be briefly discussed.

OLIGOCENE.

At the locality 1 mile south of the 12th mile on the Rock-Penal road (station 8303) a piece of hard bluish limestone containing great numbers of a species of *Nummulites* was picked up in the bed of a streamlet. This rock contains indeterminable species of corals, but

Dr. Jos. A. Cushman has examined the *Nummulites* and reports as follows: "*Nummulites* only. I should guess lower Oligocene."

At this same locality, but of entirely different appearance, a rolled specimen of *Orbicella limbata* var. *pennyi* Vaughan was collected, but it had obviously been washed out of a stratigraphically higher bed.

LOWER MIOCENE.

At the locality 1½ miles south of the 9th mile on Rock-Penal road (station 8304) the type specimen of *Goniastrea trinitatis* Vaughan, n. sp., was found where it had been thrown up by an active mud volcano. This species is very close to and may be identical with *Goniastrea canalis* Vaughan, from the Emperador limestone of the Panama Canal Zone. Because of the close similarity of the two species, it seems probable that the bed from which the type of *Goniastrea trinitatis* was derived may be the stratigraphic equivalent of either the upper part of the Culebra formation or of the Emperador limestone of the Panama Canal Zone. The upper part of the Culebra and the Emperador limestone are tentatively correlated with the Aquitanian of Europe. The Emperador limestone may be Langhian.

The fauna from Cumuto Road (stations 8299 and 9217) and Machapoorie (stations 8301 and 9220) quarries, according to Mr. Penny, represents a horizon above that of the Gasparillo and Nariva Road quarries. The only coral, however, that suggests a higher horizon is the species of *Porites* (aff. *P. porites*), but the evidence supplied by it is only suggestive, not decisive. The only other species (except *Porites* aff. *P. astreoides*) recorded from elsewhere is *Stylophora imperatoris* Vaughan,[1] originally described from the Emperador limestone of the Canal Zone.

Miss Carlotta J. Maury[2] has placed the Machapoorie quarry bed in the lower Miocene. She says: "The stratigraphic position of the Machapoorie is proved by the Brasso Valley exposure, where it is seen underlying the Manzanilla," which she correlates with the Cercado formation of the Dominican Republic. Mr. W. C. Mansfield,[3] in his paper on "Miocene Gastropods and Scaphopods from Trinidad, British West Indies," has placed the Machapoorie and Cumuto Road beds, which he believes are of the same age, in the lower Miocene beneath the material from Brasso Creek (station 8302). Because of the evidence produced by these two writers and that of *Stylophora imperatoris* Vaughan, the Machapoorie and Cumuto Road beds are placed in the lower Miocene beneath the beds of the Gasparillo and Nariva Road quarries. The coral fauna of Machapoorie and Cumuto Road quarries, almost in its entirety, is essentially new.

[1] Bull. 103, U. S. Nat. Mus., p. 334, pl. 74, figs. 1, 1*a*, 2, 3, 4, 4*a*, 5.
[2] Miocene mollusca of Trinidad: Bull. Am. Paleont., vol. 10, No. 42, p. 12.
[3] Proceedings of the U. S. National Museum, vol. 66, art. 22, pp. 1–65.

Besides *Stylophora imperatoris* Vaughan, the new species *Asterosmilia trinitatis* Vaughan is common to them. They probably represent parts of the same limestone bed.

The three species from station 9286, two of which are new, probably represent, according to Mr. Penny, beds of the same age as those of Machapoorie. The presence of *Porites* sp. aff. *P. astreoides* Lamarck at both localities helps to bear this out.

LOWER OR MIDDLE MIOCENE.

The fauna from Gasparillo (station 8297) and Nariva (stations 8298, 9198) Road quarries is rather puzzling. The foregoing table shows that the two localities have a total of 3 out of 8 species in common. The following is a brief discussion of the geologic occurrences of the more important of the species found at the two localities.

Orbicella altissima (Duncan), *O. brevis* (Duncan), and *O. cavernosa* var. *cylindrica* (Duncan) are known from the Gurabo formation of the Dominican Republic. These three species would indicate an age equivalent to the Gurabo and the Bowden (middle Miocene). However, *Psammocora gasparillensis* Vaughan, n. sp., which is common to the two quarries, is also found in the Baitoa formation of the Dominican Republic and the Thomonde of Haiti, both of lower Miocene age. *Siderastrea siderea* (Ellis and Solander) is known from the lower Miocene (Thomonde) to Recent. *Orbicella limbata* var. *pennyi* Vaughan has also been found in the Dominican Republic in the Cercado and Gurabo formations. Because of these various occurrences the beds of the Gasparillo and Nariva Road quarries are placed either in the lower or middle Miocene above the beds of Machapoorie and Cumuto Road. The piece of *Orbicella limbata* var. *pennyi* Vaughan picked up 1 mile south of the 12th mile on the Rock-Penal road (station 8303) was probably washed out of a bed of the same age.

MIDDLE MIOCENE.

The specimens from 1 mile south of the railway station at Brasso (station 8302) were washed out of the flood-wash from the stream bank. They are placed in the middle Miocene because of the following data:

The form of *Madracis* (*M.* sp. aff. *M. mirabilis*) found south of Brasso is present in the middle Miocene yellow marl in the gorge of Yumurí River at Matanzas, Cuba, where it is associated with corals that can be correlated with the Bowden marl of Jamaica, while the *Thysanus* from 1 mile south of Brasso resembles the young of species found at Bowden and Matanzas.

Miss Maury (op. cit., p. 11) states that "Other Manzanilla species are also found in * * * Brasso Creek, but in the creek they are not *in situ*." It is *possible* that her specimens came from the same bed

as the corals of station 8302. She places the Manzanilla in the upper part of lower Miocene. It is also *possible* that the specimens from station 8302 have been washed from beds of the same age as Miss Maury's Brasso beds, which she regards as middle Miocene.

DISCUSSION OF SPECIES.

Sphenotrochus trinitatis Vaughan, new species.

Plate 1, Figures 1 and 1*a*.

Description of the holotype.—Corallum cuneiform; scarcely increasing upward in diameter in plane of longer calicular diameter, slightly and gradually increasing upward in diameter in plane of shorter calicular diameter; base emarginate, sinus gently rounded. Height, 13 mm.; greater diameter of corallum at the calice, 9 mm.; lesser diameter of the corallum at the calice, 5 mm.

Costæ strongly alternating in size on the upper part of the corallum and nearly all of the small costæ extend to the base. The total number of large costæ is 24. These are thick, rounded in profile, granulate, and prominent. All the costæ, except those at the ends of the longer transverse axis of the corallum and the three large costæ next each end of the longer axis, on each face, decrease in thickness toward the base. The 24 costæ above mentioned widen toward the base, as in *Platytrochus stokesi* (Lea). The smaller costæ, which are also 24 in number, are thin, acute, and not so tall as the large costæ. All costæ, except those near the ends of the longer axis of the corallum decrease in size toward the base and some of those near the middle of the faces of the corallum disappear before the base is reached.

Septa, 48; margins of primaries and secondaries exsert about 1.2 mm., margins of tertiaries not so tall, margins of quaternaries not prominent. The primaries and secondaries extend to the columella; tertiaries somewhat shorter; quaternaries much shorter.

Columella a compressed axial plate, with several, apparently 5 or 6, crenulations along its top.

Locality and geologic occurrences.—Trinidad, station 8301, Machapoorie Quarry; lat. 10° 27′ 25″ N., long. 61° 14′ 35″ W.; from bed considered to be of Langhian Miocene age; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353645.

The species most nearly related to *Sphenotrochus trinitatis* is *Sphenotrochus auritus* Pourtalès,[1] which is smaller and has differently ornamented costæ.

Sphenotrochus brassensis Vaughan, new species.

Plate 1, Figures 2 and 2*a*.

Description of the holotype.—Corallum small, cuneate, base convexly curved, not emarginate, in the plane of the longer transverse axis of the corallum. Height 3.7 mm.; greater diameter of corallum at calice, 3.8 mm.; lesser diameter of corallum at calice, 1.9 mm.

Costæ low, flattened along the summit. Those at the ends of the longer transverse axis and either two or three costæ on each face next each end of the longer axis are wide and are composed of granulations compressed and elongate transversely to the costal courses. Near the base the granulations may be confused so that the costal courses can not be clearly traced. About 7

[1] Mus. Comp. Zool. Harvard Coll. Mem. vol. 4, p. 37, pl. 6, figs. 14, 15, 1874.

costæ on each face are definite from their beginnings; they are simple slightly above the base, but higher up there is tendency for each to be formed of two rows of granulations.

There are 24 septa, 12 of which extend to the columella, and 12 are very short.

Columella, a thickish axial plate.

Locality and geologic occurrence.—Trinidad, station 8302, 1 mile south of Brasso; lat. 10° 23′ 45″ N., long. 61° 19′ 18″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353646.

The species most nearly like *Sphenotrochus brassensis* is an unpublished species from Bowden, Jamaica. The granulations along the costæ in the latter species are elongate parallel to the courses of the costæ, except a very few costæ near the base; the corallum is not so much compressed, and the base is not so wide as in *S. brassensis*. The two species differ markedly both in form and the ornamentation of the costæ.

Placocyathus trinitatis Vaughan, new species.

Plate 1, Figures 3, 3*a*, 3*b*, and 4; Plate 2, Figure 9.

Description of cotypes.—Corallum flabellate, very slightly curved in the plane of the shorter transverse axis of the calice, attached by a small, pointed base, above which there are no lateral crests. Cotype No. 1: Greater diameter of corallum at the calice 19 mm.; lesser diameter of the corallum at the calice about 7 mm. (corallum somewhat crushed, measurement not precise); height of corallum 19 mm. Cotype No. 2: Greater diameter of corallum at the calice, 18.5 mm.; lesser diameter of corallum at the calice 8.5 mm.; height of corallum a little more than 20 mm., about 21 mm. Upper edges of calicular margin subplane; slight longitudinal sinuosities. Calice moderately deep, probably between 5 and 7 mm., not definitely measurable in the cotypes.

Wall rather thin at the upper edge but stout lower down; interseptal loculi solidly filled with stereoplasm near the base; wall becomes more or less coated externally. Costæ correspond to all septa around the calice, where they may be rather low but alternately more and less prominent, or every fourth costa may be decidedly more prominent than the intervening three costæ. Lower down on the corallum the costæ are equal or subequal, low, and flattish.

Because the specimens are damaged the septa can not be counted around the calicular margin, but the number of them can be closely estimated—there are about 74 septa in cotype No. 2. On a cut transverse surface of cotype No. 2, where the greater diameter is 14.5 mm., there are about 60 septa. Of these 60 septa nearly half either extend directly to the columellar area or are joined to the columella by pali. Pali are well developed, but their details are obscure, apparently in two crowns, present before the septa intermediate in cycle between the first two cycles and the members of the last cycle. I am not sure that they are absent before the primaries and secondaries.

The columella is a contorted axial plate; it appears in a transverse section of cotype No. 2 that it may initially be formed by the fusion of an axial row of trabeculæ.

No trace of endothecal dissepiments was seen.

Locality and geologic occurrence.—Trinidad, station 8301, Machapoorie Quarry; collected by F. W. Penny.

Cotypes.—U. S. Nat. Mus. Cat. No. 353647.

Stylophora imperatoris Vaughan.

Plate 1, Figures 5, 5*a*, 6, and 7; Plate 2, Figure 1.

1919. *Stylophora imperatoris* Vaughan, U. S. Nat. Mus. Bull. 103, p. 334, pl. 74, figs. 1, 1*a*, 2, 3, 4, 4*a*, and 5.

Description of specimen No. 1 (plate 1, figures 5, 5*a*, 6, and 7).—Corallum composed of branches that are strongly compressed or of branches of subelliptical cross-section. This specimen, which is bifurcate, has been flattened by pressure and is thinner than it was originally. It is 7 mm. thick and 41 mm. wide. As the specimen is broken on both its upper and lower ends, the original length is unknown; the present maximum length is 37 mm. The faces of the branches may be plane or with low tuberosities.

Calices from 1 to 1.2 mm. in diameter; intervening coenenchyma from 0.75 mm. to 1.5 mm. across, usually about 1 mm. Calicular rim distinct, slightly elevated; upper margin ranging from slightly more prominent than the lower margin to a fairly well developed, costate upper lip.

Septa, 6 strongly developed primaries that fuse to the columella, the directives a little more prominent than the other primaries; secondaries slightly developed, rudimentary, or absent; usually a few, two or few more, small secondaries may be recognized in each calice. The margin of each primary septum is slightly exsert, and corresponding in position to secondary septa there is between each pair of primaries either a short costa or a granule; tertiary costæ or granules are present around many calices.

Columella, a pointed style, reaching to or almost to the level of the calicular mouth.

Coenenchyma dense, surface coarsely granulate. In the intercorallite area there is usually either a ridge or a small groove. Scattered granulations may occur between the ridge or groove and the calicular margins. The granulations are nipple-shaped, their summits rather rounded—not finely pointed, as is usual in *Stylophora granulata* Duncan.

Two other specimens from the same locality as the one above described are represented by plate 1, figures 6 and 7. The calices of the smaller, the younger, of these specimens are somewhat smaller than in specimen No. 1, the shorter diameter of some being 0.75 mm.; an upper calicular lip is well developed and on it there are thin, sharp, rather prominent costæ; and the granules on the coenenchyma are rather sharp pointed.

Another specimen (plate 2, fig. 1), from Machapoorie Quarry, is a more elongate branch, with few nodular swellings on one side, while they are well developed on the other. The calices are more elliptical in outline and slightly longer, up to 1.5 mm., than is usual in specimen No. 1. An upper calicular lip is particularly well developed on the side of the branch where nodular protuberances are present.

Localities and geologic occurrence.—Trinidad; station 8299, Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W. Stations 8301 and 9220, Machapoorie Quarry; lat. 10° 27′ 25″ N., long. 61° 14′ 35″ W. Collected by F. W. Penny. Also Emperador limestone (Canal Zone) and Anguilla formation (island of Anguilla).

The foregoing description and the figures of these Trinidad specimens are rather elaborate, as I wish to make obvious the reasons for the proposed identification. Reference to the original description of *Stylophora imperatoris* shows no important difference, except that the Trinidad specimens are better preserved and a few details, such as the height of the columella, are included in the description of them. A review of the original material from the Emperador limestone found in them similar details and a similar range in varia-

tion. I have been able to discover no criteria for separating the two sets of specimens into different species.

Madracis sp. aff. M. mirabilis (Duchassaing and Michelotti).

1861. *Stylophora mirabilis* Duchassaing and Michelotti, Mém. Corall. Ant., p. 62 (of reprint), pl. 9, figs. 6 and 7.
1919. *Madracis mirabilis* Vaughan, U. S. Nat. Mus. Bull. 103, p. 345.

Three small fragments of *Madracis* are similar to specimens which have been referred to as a variety of *M. mirabilis*, but as specimens from different localities accumulate the probability increases that a separate species should be recognized.

Locality and geologic occurrence.—Trinidad, station 8302, 1 mile south of the railroad station at Brasso, washed out of the stream bank; lat. 10° 23′45″ N., long. 61° 19′ 18″ W.; collected by F. W. Penny. Also as follows: Gatun formation, Station 8305, Swan Cay, Costa Rica, collected by A. Olsson; Limon, Costa Rica, collected by H. Pittier (U. S. Nat. Mus. Cat. No. 324796). Marl (age of the Bowden marl), gorge of Yumurí River, Matanzas, Cuba, collected by T. W. Vaughan (U. S. Nat. Mus. Cat. No. 324798). Gurabo formation, station 8544, Dominican Republic.

Asterosmilia trinitatis Vaughan, new species.

Plate 2, Figures 2, 2*a*, 2*b*, and 3.

Description of holotype.—Corallum cuneate, straight, attached by a rather thick, short pedicel, above which are low, lateral crests that either become obsolete or nearly obsolete at a height of about 1 cm. above the base. Greater diameter of corallum at the calice 16.5 mm.; lesser diameter of corallum at the calice 8 mm.; height of corallum 19 mm. Upper edges of calicular margin subplane; depth of calice moderate, precise measurement not practicable, about 3 mm., perhaps 4 mm.

Wall stout, with some porcellanous coating. Costæ correspond to all septa, distinct but not prominent; subequal, with narrow intercostal spaces around the edge of the calice; alternately large and small lower down on the corallum. Costal edges acute or rounded, granulate near and at the calicular margin, lower down the granulations are obscured by secondary deposit.

Septa rather thick, especially at the wall; margins only slightly prominent, those of the principal septa exsert about 1 mm. Primaries and secondaries extend to the columella; members of the higher cycles shorter according to cycle. Septal margins obscurely dentate, subentire. Septal faces with narrow, granulate ridges; 8 ridges on a large septum within 2 mm., or 4 ridges to 1 mm. Prominent, erect pali stand before the inner ends of the penultimate or the antepenultimate septa—in part of one system there is a palus before a penultimate septum, while in part of a system near one end of the calice there is a palus before an antepenultimate septum.

As the endothecal and columellar features are not exhibited by the holotype, descriptions of them will be based on a paratype.

Description of paratype.—In general features the paratype is similar to the holotype, except that its greater diameter is slightly less in proportion to the lesser diameter. Greater diameter of corallum at calice 12 mm.; lesser diameter of corallum at calice 8.5 mm.

The columella is compressed, composed of fused axial trabeculæ. There is considerable fusion of the inner ends of the higher to the sides of the lower cycles of septa. A very few endothecal dissepiments are present.

Locality and geologic occurrence.—Trinidad, stations 8299 and 9217, Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61°, 13′ 25″ W.; some poorly preserved

specimens from Machapoorie Quarry. Station 8301; collected by F. W. Penny and J. A. Bullbrook.

Holotype.—U. S. Nat. Mus. Cat. No. 353648.

Paratype.—U. S. Nat. Mus. Cat. No. 353649.

The species most nearly related to *Asterosmilia trinitatis* is *A. compressa* Vaughan from the Dominican Republic. *A. compressa* is relatively wider, the pedicel is smaller, and the lower part of the corallum is slightly curved in the plane of the shorter transverse axis of the calice.

Asterosmilia machapooriensis Hoffmeister, new species.

Plate 2, Figures 4, 4*a*, 4*b*, 4*c*, and 5.

A group of specimens from station 8301, Machapoorie quarry, differ from those which have been referred to *A. trinitatis* Vaughan from the same locality. The following description is based on two of them which have been taken as cotypes:

Cotype No. 1.—Corallum cornute, only slightly curved in the plane of the shorter transverse axis. It is 33 mm. long and is shaped like a slightly bent somewhat flattened cone. The calice is elliptical, the greater diameter 17 mm., the lesser 11 mm. There are no crests. At the base there is evidence of a rather large detachment scar.

The costæ are rather well developed. At the calicular rim every sixth one is more prominent than the others, the central one between these is not quite so prominent, and there are two small, equal-sized costæ on each side of this central one. This formula appears to hold only near the edge of the calice. At 2 or 3 mm. below the edge the two pairs of small equal costæ seem to merge into one another. This makes every fourth costa taller than the others, the one midway between them a little less prominent and only one smaller costa on each side of this central one instead of two. In general, over most of the corallum, every fourth costa is taller than the others. The wall is moderately thick. The specimens are not sufficiently perfect to tell whether there are granulations on the costæ.

There are 18 large septa of nearly equal size which reach the columella. These 18 septa correspond to the prominent costæ. Alternating with them are 18 slightly thinner septa which usually also reach to the columella. Between these latter septa and the 18 larger ones there are 36 small subequal septa, none of which reach the columella. The septal margins are in a very worn condition. It appears that the septal faces bear some granulations and that the septal edges are obscurely dentate. The endotheca is well developed. A row of dissepiments from 2 to 3 mm. from the calicular edge go all around the calice. They are rather thick and seem to go downward at a large angle from the horizontal. The pali seem to be well developed and appear to be present before each of the large septa, although they are rather obscure.

The columella is spongy.

Cotype No. 2 (plate 2, fig. 5).—The features of the septa given in the foregoing description can be seen on only part of the corallum. Cotype No. 2 was cut transversely 7 mm. from the calicular edge and the cut surfaces polished. The calicular arrangement as mentioned above can be plainly seen all around the corallum.

This species is somewhat similar to *A. profunda* Duncan. It may possibly represent young specimens of it, but I doubt this very much. *A. profunda* is much larger, has 5 complete cycles of septa, and is more curved than *A. machapooriensis.*

Locality and geologic occurrence, Trinidad, station 8301: Machapoorie Quarry; lat. 10° 27′ 25″ N., long. 61° 14′ 35″ W.; collected by J. A. Bullbrook.

Cotype No. 1.—U. S. Nat. Mus. Cat No. 353650.

Cotype No. 2.—U. S. Nat. Mus. Cat. No. 353651.

Antillia sawkinsi Vaughan, new species.

Plate 2, Figures 6 and 6*a*.

The following description is based on the holotype and four paratypes:

Corallum slightly compressed-turbinate or slightly compressed-subcylindrical, with a small basal attachment. Dimensions and number of septa are given in table 2.

TABLE 2.—*Dimensions in millimeters and number of septa of Antillia sawkinsi.*

Specimen.	Greater diameter.	Lesser diameter.	Height.	Number of septa.	Notes.
No. 1.....	27	22	16	119	About 26 principal septa.
2.....	27	20	27	126	About 18 principal septa.
3.....	37	29	24	.....	Calice damaged.
4.....	30	28	34	122	Inner edges of septa broken.
[1]5.....	32	24	43	141	About 26 principal septa.

[1]Holotype.

Corallum wall moderately strong, more or less covered by encircling, pellicular, detachable, finely striate epitheca which is laid down over the costal edges. Costæ correspond to all septa, not very prominent, as a rule alternately larger and smaller, but are equal or subequal in places. Height of tall costæ about 0.5 mm.; thickness, about 0.5 mm. The sides of the costæ are vertical; the edges with strong granulations which are compressed in a plane transverse to the costal courses, about 10 granulations within 5 mm. on a large costa, 12 to 15 granulations within 5 mm. on a smaller costa.

Depth of calice, 6 mm. The total number of septa and the approximate number of the principal septa are given in table 2. The members of the youngest cycle in the different systems are small, even rudimentary. Within the wall the septa are lanceolately thickened, but within the calice they are rather thin. Over the wall they are alternately more and less prominent, the margins of the larger septa exsert as much as 2 mm. The tops of the septal arches are serrately dentate, 7 teeth within 4 mm.; within the calice the dentations are smaller. The septal faces are ridged; a low ridge emerging on the septal margin as a septal tooth; granulations along the ridges, especially along the summits. The inner septal lobes are very narrow.

Columella trabecular, spongy, rather small, 2.5 mm. wide by 6.5 mm. long in specimen No. 5 of the table.

Endothecal and exothecal dissepiments well developed. The exothecal dissepiments occur between the costæ.

Locality and geologic occurrence.—Trinidad, Cumuto Road, mile 17; station 8299, 9217; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353652.

Paratypes.—U. S. Nat. Mus. Cat. No. 353653.

Antillia sawkinsi has in proportion to its size more numerous septa and it has more coarsely dentate septa than *A. dubia* (Duncan), the only species with which comparison seems to be needed.

Antillia bullbrooki Hoffmeister, new species.

Plate 2, Figures 7, 7*a*, 8, and 8*a*.

Seven specimens of this species were collected and the description is based on the holotype unless otherwise designated.

Corallum a compressed cone with pointed base; calicular border elliptical. Height of corallum 36 mm.; greater diameter of calice 31 mm., lesser diameter 21 mm. The epitheca is rather poorly developed, extends as porous sheet half way up corallum, and can be seen as irregular frayed bands at various intervals higher up. The costæ correspond to the septa and are rather prominent, clearly visible even when covered by epitheca. They are subequal, 0.75 mm. high and about 0.5 mm. thick. The costal edges are rather smooth and possess no prominent granulations. This may possibly be due to a worn condition but is characteristic of all the specimens.

The depth of the calice is 6 mm. The septal arches are sharply curved. The septa alternate in size over the wall and are decidedly thickened in the wall. The septa are thicker than those of *Antilla sawkinsi* Vaughan. There are 90 septa in all, about 26 principal ones, which reach the columella, and 26 thinner ones, some of which also reach the columella and the remainder of which join the longer septa near the columella. The septal faces are marked with parallel rows, 0.5 mm. apart, of medium-sized granulations. These rows appear to parallel approximately the outer edges of the septa, i. e., the costæ.

The columella is covered in the holotype, but in the paratype it is revealed as a spongy mass made up of the tangled ends of septa. In this latter specimen, which is shown on plate 2, figures 8 and 8*a*, the greater diameter of the columella is 8 mm. and the lesser 2.5 mm.

The endothecal dissepiments are well developed. The exothecal dissepiments are obvious between the costæ.

Locality and geologic occurrence.—Trinidad. Station 9286. Quarry 0.25 mile down Hindustan Junction branch road, which runs south from mile 13.5 on the San Fernando-Mayaro main road; Amphistegina limestone. Collector, F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353675.

Paratype.—U. S. Nat. Mus. Cat. No. 353676.

The other specimens are variable in size, shape, and the number of septa. Table 3 gives a few dimensions in millimeters.

Table 3.

Specimen No.	Greater diameter of calice.	Lesser diameter of calice.	Height.	Number of septa.
2	20	15	18	74
4	32	25	26	98
5	35	26	22	92
6	36	28	22	Approximately 100
7	52	33	61	Calice covered up

This species is similar in many respects to *A. sawkinsi* Vaughan, but differs from it in the following ways:

1. Septa are thicker.
2. Septa not so numerous.
3. Very few costæ alternate in size; as a rule they are subequal.

4. Costæ not so distinctly marked with granulations.
5. Shape of corallum. Corallum usually comes to a sharp point. In typical *A. sawkinsi* the circumference of the corallum does not change appreciably until near the base, where it quickly tapers to a rounded end.

Orbicella limbata var. pennyi Vaughan, new variety.
Plate 3, Figures 1, 1*a*, and 1*b*.

Description of holotype.—Corallum massive, with a domed or flattish upper surface, attaining a horizontal diameter of 21 cm. and a thickness of 13.5 cm.

Calices from 2.75 to 3 mm. in diameter; distance apart from 1 to 2 mm.; depth about 1.5 mm. Corallite walls stout. Intercorallite area strongly costate; the costæ corresponding to the primary and secondary septa are more prominent than those corresponding to the tertiaries and extend to meet costæ from neighboring corallites.

Septa normally 24, in 3 cycles; in some calices there are 26 septa, i. e., there are in these calices 2 quaternary septa. All septa somewhat thickened in the wall. The primaries are the thickest septa and extend to the columella; the secondaries are thinner than the primaries and as a rule do not reach the columella. The contrast in length and thickness of the primary septa as compared with the secondaries is among the distinguishing characteristics of this species. A crown of paliform teeth on the inner ends of the primaries stands just interior to a crown of similar teeth on the inner ends of the secondaries and on the inner end of the long tertiary where there is a quaternary septum on each side of it. The members of the last cycle of septa are very short and have thin inner edges. The margins of the primaries are moderately prominent, more exsert than those of secondaries; margins of the tertiaries and of the occasional quaternaries the least prominent. The inner septal edges are steep. The presence of paliform teeth has been mentioned. Septal faces with a few rather coarse granulations.

Columella composed of a lax tangle of processes, well developed, from 1 to 1.5 mm. in diameter; it forms a flattish floor surrounded by the inner edge of the long septa.

Exotheca and endotheca well developed. The exotheca tend to form intercorallite platforms or collars around the corallite tubes.

Localities and geologic occurrence.—Trinidad, as follows: Holotype, station 8298, Nariva Road Quarry; lat. 10° 23′ 40″ N., long. 61° 17′ 10″ W. Other specimens: Station 8297, Gasparillo Quarry; lat. 10° 19′ 50″ N., long. 61° 25′ 10″ W. Station 9198, Nariva Road, mile 0.25. Station 8303, rock, 1 mile south of mile 12 on Rock-Penal Road; lat. 10° 7′ 25″ N., long. 61° 20′ 45″ W.; picked up in the bed of a streamlet. All specimens collected by F. W. Penny except one by J. A. Bullbrook from station 9198.

Dominican Republic: Rio Cana, zone H, collected by Miss C. J. Maury; collected at numerous localities by Vaughan and Cooke.

Holotype.—U. S. Nat. Mus. Cat. No. 353654.

This variety differs from typical *Orbicella limbata* (Duncan) mainly in its growth form. *O. limbata* grows as divided columns or lobes, whereas var. *pennyi* is massive. The latter also appears to have somewhat smaller calices, but this is so variable in the different specimens that it can not be regarded as a definite distinction. The two forms are identical in septal characters. *Orbicella annularis* (Ellis and Solander) is similar to *O. limbata* var. *pennyi* in its growth form, the size of its calices, and the number of septa, but it differs from the latter by its shorter and thinner secondary septa, which are clearly differentiated in length and thickness from the primaries.

The specimen collected by Miss C. J. Maury from Rio Cana, zone H, Dominican Republic (U. S. Nat. Mus. Cat. No. 353655) differs in no noteworthy particular from the Trinidad specimens, but, as it has not been changed by fossilizing processes, the details of its endotheca and exotheca are perfectly preserved. The endothecal dissepiments are thin and are relatively flat on their upper surface, they sag downward in the central part of the corallite; between 13 and 14 were counted in a vertical linear distance of 5 mm. The exothecal dissepiments are thicker than the endothecal dissepiments; between 8 and 9 within 5 mm. in vertical distance. From place to place, without regular spacing, solid intercorallite platforms, which may be 1.5 mm. thick, are developed perpendicular to the vertical axes of the corallites.

Orbicella altissima (Duncan).

Plate 3, Figures 2 and 2*a*.

1867. *Heliastraea altissima* Duncan, Geol. Soc. London Quart. Jour., vol. 24, pp. 12, 24 pl. 2, fig. 3.
1919. *Orbicella altissima* Vaughan, U. S. Nat. Mus. Bull. 103, pp. 363, 379.

The following are notes on the specimen identified as *Orbicella altissima:*

The corallum is massive, with a flattish upper surface.

Calices subcircular, from 3.5 to 4.5 mm. in diameter, from 0.5 mm. to 2.5 mm. apart; depth probably about 2 mm. Calicular margins more or less raised. As the upper surface of the specimen is worn, the characters of the calicular margins and of the intercorallite areas are not exhibited. However, a polished transverse section of the corallites shows the presence of strongly alternating costæ; those corresponding to the septa older than the last cycle are tall and meet those of adjacent corallites; they are thin, except near the wall, where they thicken considerably. The last cycle of costæ are relatively short, thin toward their edges but thick at the wall. Wall stout.

Septa, in a corallite 4.5 mm. in diameter, 38 in number; in another corallite 4 mm. in diameter there are 36 septa. Usually the primaries may be distinguished by their greater thickness and length. Members of the last cycle short and thin. All septa show more or less lanceolate thickening in the wall. The inner ends of the longer septa bear paliform teeth.

Columella composed of interlacing trabeculæ, fairly well developed, about 1.5 mm. in diameter.

Locality and geologic occurrence.—Trinidad, station 8297, Gasparillo Quarry; lat. 10° 19′ 50″ N., long 61° 25′ 10″ W.; collected by F. W. Penny. U. S. Nat. Mus. Cat. No. 353656. A specimen which probably belongs to this species was found in the Dominican Republic, station 8542, in the Gurabo formation; T. W. Vaughan and C. W. Cooke, collectors.

The specimen above described differs in no noteworthy particular from Duncan's description of *Orbicella altissima*, which name is, therefore, applied to it. The type of the species was collected at St. Croix, Trinidad, and probably is somewhere in London, but I did not see it in the Museum of the Geological Society of London or in the British Museum (Natural History).

Orbicella cumutensis Hoffmeister, new species.

Plate 3, Figures 3 and 3*a*.

A small fragment containing very well preserved calices was found in the quarry of the Cumuto Road, mile 17.

Corallum probably massive; fragment irregular in shape, 40 mm. long, 22 mm. wide, and 10 mm. thick.

Corallites subelliptical, appear to be slightly distorted. Calices small; average calice has larger diameter of 3.25 mm. and lesser one of 3 mm. They are rather crowded; distance between calicular rims ranges from less than 0.5 mm. to 2 mm.; unusually 1 mm. apart. The calicular rims stand 1 mm. or more above the plane of the corallum and the calices are about 1 mm. in depth.

The septa vary in number according to the size of the calices. In a calice of the average size there are 16 septa, two full cycles, and 4 of the third. All of the septa are so nearly of the same thickness that it is difficult to distinguish the different cycles by this character. The septa of the first cycle are slightly longer than those of the higher cycles. The septal margins of the first cycle are exsert nearly 0.5 mm. They arch above the wall, extend 0.5 mm. into the calice, and plunge nearly perpendicularly to the bottom, where they at that level reach out to join the columella. The septal margins of the second cycle of septa slope toward the bottom of the calice at a closer distance to the wall than those of the first cycle. The septa of the second cycle are only slightly smaller than those of the first cycle and there is very little difference in the sizes of the second and third. In one calice, which is half destroyed, the septa appear to be arranged as if there were 24 present, three full cycles. In some calices two or three rudimentary septa appear between the larger ones. The septa are all thickened in the wall. The septal faces bear granulations and the margins are somewhat serrate.

Prominent costæ outside the calice correspond to all of the septa within. They are subequal, bear granulations on their edges, and either join or alternate with those of the adjoining calices. In places there are between the larger costæ rudimentary costæ to which there are no corresponding septa.

Prominent pali can be seen in many calices and appear to be in front of the septa of the first two cycles. The columella is large and appears to be papillate. The endothecal and exothecal dissepiments are well developed.

Locality and geologic occurrence.—Trinidad, station 9217, Cumuto Road, mile 17, second quarry; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W. Collected by J. A. Bullbrook.

Holotype.—U. S. Nat. Mus. Cat. No. 353678.

This species differs from *O. limbata* var. *pennyi* Vaughan in that it has fewer septa and that the septa of the first and second cycles are of nearly the same thickness.

Orbicella trinitatis Vaughan, new species.

Plate 4, Figures 1 and 1*a*.

Growth form of corallum massive.

Corallites subelliptical in transverse outline. Diameter of calices ranges from 3 by 4 mm. to 4.5 by 5.75 mm., measured between thecal summits. Distance between calices from 1 to 2.5 mm. Calicular rims elevated as much as about 1.5 mm. Depth of calices about 1.5 mm. The free corallite limbs slightly decrease in diameter upward.

The number of septa in a calice 3.5 by 4.75 mm. in diameter is 48, or 4 complete cycles. All the septa are relatively thin, but are somewhat thickened in the wall. The primary and secondary septa extend to the columella, but the primaries are the larger; the tertiary septa are much shorter; the quaternary septa are rudimentary. In larger calices the secondaries are nearly equal to the primaries in size. The margins of the primaries are exsert as much as 0.5 mm.; the secondaries are almost as exsert; the tertiaries are less exsert; the quaternaries are low. Outside the corallites the septa are prolonged into rather thin, roughly dentate costæ; most of which, except those corresponding to the last cycle of septa, continue on the intercorallite areas until they

meet the costæ from adjoining corallites. Within the calices there is a strong, rather wide, erect paliform tooth on the inner end of each primary and secondary septum. A few fairly large granulations on the septal faces.

Columella rather large, greater transverse diameter about 1.5 mm., composed of processes from the inner ends of the septa.

Endothecal and exothecal dissepiments well developed, but their details are obscure in the type, because of recrystallization of its substance.

Locality and geologic occurrence.—Trinidad, station 8299, Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W., collected by F. W. Penny. Dominican Republic, station 8668, Baitoa formation; D. D. Condit, collector.

Holotype.—U. S. Nat. Mus. Cat. No. 353657.

There is no other American species of *Orbicella* that has 4 complete cycles of septa in so small calices as *O. trinitatis*—in fact, the species is unique. *O. altissima* (Duncan) is the most nearly related species.

Orbicella cavernosa var. cylindrica (Duncan).

1863. *Astraea cyclindrica* Duncan, Geol. Soc. London Quart. Jour., vol. 19, p. 434, pl. 15, fig. 8.

1919. *Orbicella cavernosa* var. *cyclindrica* Vaughan, U. S. Nat. Mus. Bull. 103, pp. 363, 385, pl. 89, fig. 2.

The specimens from Trinidad are typical *O. cavernosa* var. *cylindrica*. Diameter of corallites, 7 mm. (measured between outsides of corallite tubes); septa, 38 in number; costæ corresponding to the last cycle of septa, small.

Locality and geologic occurrence.—Trinidad, station 8297, Gasparillo Quarry; lat. 10° 19′ 50″ N., long. 61° 25′ 10″ W.; collected by F. W. Penny; U. S. Nat. Mus. Cat. No. 353658. This variety, originally described from Santo Domingo, was collected by Miss C. J. Maury in Dominican Republic, on Rio Gurabo, zone D; U. S. Nat. Mus. Cat. No. 353659.

Orbicella brevis (Duncan).

1864. *Astraea brevis* Duncan, Geol. Soc. London Quart. Jour., vol. 20, p. 37, pl. 4, figs. 3*a* and 3*b*.

1919. *Orbicella brevis* Vaughan, U. S. Nat. Mus. Bull. 103, pp. 364, 391, pl. 97, fig. 1.

One specimen from Trinidad is very nearly typical *Orbicella brevis*. Its calices are from 4.5 to 5.75 mm. in diameter; septa in a calice 5.5 mm. in diameter 34 in number. Costæ flattish, thick, subequal around the calicular margins; strongly alternating lower down on the corallite limbs, the larger costæ becoming tall and having rather sharp edges.

Locality and geologic occurrence.—Trinidad, station 8298, Nariva Road Quarry; lat. 10° 23′ 40″ N., long. 61° 17′ 10″ W.; collected by F. W. Penny; U. S. Nat. Mus. Cat. No. 353660. Dominican Republic, stations 8539, 8540, 8541, 8545, Gurabo formation; T. W. Vaughan and C. W. Cooke, collectors.

Goniastrea trinitatis Vaughan, new species.

Plate 4, Figures 2 and 2*a*.

Description of holotype.—Corallum massive, upper surface flattish; 80 mm. wide and 22 mm. thick.

Calices joined directly by solid thick walls that are rather thin on their upper edges but thicker below; polygonal, more or less deformed, rather shallow; lesser diameter of fully grown calices from 2 to 3 mm.; length, from about 2 mm. to 3.5 mm.

Septa in fully grown calices range from 24 to 34 in number, 34 in a calice 2.5 mm. wide by 3.5 long. As a rule the septa are alternately long and short, the long ones reaching the columella, but next the ends of the longer transverse axis of a calice there may be three shorter between two longer

septa. The inner edges of the small septa are either free or are fused to the sides of a member of a lower cycle. Within the wall the septa are rather thin, not so thick as the width of the interseptal loculi, but they are thicker in the wall. The outer ends of the septa are either opposite or alternate, where alternate the summit of the wall is zigzag in plan. The septal margins are broken, but it seems that there were paliform lobes on the inner ends of the large septa. Septal faces with rather coarse granulations.

Columella false, fairly well developed, about 1 mm. wide.

Endothecal dissepiments well developed; in one place there are 3 within 1.25 mm., or the distance apart there is about 0.6 mm.

Locality and geologic occurrence.—Trinidad, station 8304, 1.5 miles south of the ninth mile on the Rock-Penal road, thrown up by an active mud volcano; lat. 10° 6′ 55″ N., long. 61° 22′ 10″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353661.

Goniastrea trinitatis makes the fourth species of *Goniastrea* to be described from the Tertiary formations of America. The other species are *Goniastrea variabilis* Duncan from the Eocene St. Bartholomew limestone; *G. reussi* (Duncan) (originally described as *Stephanocoenia reussi*) from the middle Oligocene Antigua formation of Antigua; and *G. canalis* Vaughan from the Emperador limestone of the Panama Canal Zone. All these species are represented in the United States National Museum. *G. variabilis* has much larger calices than any of the other species. *G. reussi* has calices only slightly larger than those of *G. trinitatis*, but it is readily distinguishable by the absence of small septa between the large septa. *G. canalis* has calices slightly larger on the average than *G. trinitatis*, but in the size of the calices the two species overlap, for the lesser diameter of many calices in *G. canalis* is only 3 mm. The real difference between these two species consists in the larger number of septa, that is, the more crowded septa, in *G. canalis*. In a calice of *G. canalis* that is 3 mm. wide and 3 mm. long there are 42 septa, while a calice of *G. trinitatis* 2.5 mm. wide by 3.5 mm. long has 34 septa. The possibility that *G. trinitatis* is only a variant of *G. canalis*, of course, should be recognized.

Thysanus species, juv.

Four young specimens that are not specifically identifiable were obtained at the following locality:

Locality and geologic occurrence.—Trinidad, station 8302, 1 mile south of the railroad station at Brasso, washed out of the stream bank; lat. 10° 23′ 45″ N., long. 61° 19′ 18″ W.; collected by F. W. Penny; U. S. Nat. Mus. Cat. No. 353662.

Thysanus is known to range in American Tertiary formations from the horizon of the lower Miocene Cercado formation to the Pliocene Caloosahatchee marl.

Mycetophyllia bullbrooki Vaughan, new species.

Plate 4, Figure 3.

Description of holotype.—Corallum large, massive, upper surface flattish. The holotype is only a segment of a corallum, but it is 25 cm. long, 16 cm. wide, and 17.5 cm. thick.

Calices large, shallow, not definitely delimited, joined together by continuous septo-costæ. Diameter between the middles of the intercorallite areas ranges from 15 to 25 mm.; distance between calicinal centers from 14 to 26 mm. Calicular cavities shallow, range in depth from almost superficial to about 3.5 mm. Intercorallite areas flattish or slightly and gently arched; crossed by subequal, thin, distant, erect, rather coarsely dentate septo-

costæ. Height of septo-costæ ranges up to about 2 mm., usually somewhat less; from 6 to 9 septo-costæ to 1 cm.; thickness from about 0.25 to 0.5 mm. The dentations are much damaged, but in places there are 3 or 4 teeth within 3 mm., or the teeth are nearly 1 mm. wide at the base.

Septa relatively few, thin and distant. A large calice has about 28 septa, of which about 16, a little more than half, reach the columella. Margins dentate, dentations decreasing in size toward the columella.

Columella vesicular, false, rather small, that of one calice about 2 by 3 mm. in diameter; about 2 mm. is nearly an average diameter.

Dissepiments greatly developed but thin; they reach the corallum surface between the septo-costæ in the intercorallite areas. About 12 dissepiments were counted between costæ in a vertical distance of 1 cm.

Locality and geologic occurrence.—Trinidad, station 8299, Cumuto Road, mile 17, lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353663.

The type species of *Mycetophyllia*, *M. lamarckana* Milne Edwards and Haime, is widely distributed in Florida and the West Indies. I have never seen a specimen of *M. lamarckana* of so large a size and of so massive a growth form as the holotype of *M. bullbrooki*. Furthermore, there are in *M. lamarckana* well-developed, rather tall or decidedly tall collines between which are calicinal centers that are connected one with another by tall, thin, distant, erect, dentate septo-costæ. The two species seem very distinct.

Pavona pennyi Vaughan, new species.

Plate 5, Figures 3, 3*a*, and 3*b*.

Description of holotype.—Holotype, a segment of a unifacial plate, 57 mm. long, 45 mm. wide, and from 5 to 10 mm. thick.

Outer surface entirely devoid of epitheca, marked by low, crowded, fine costæ, about 24 costal markings within 5 mm. These markings are more or less in pairs and seem to be formed by the peripheral bifurcation of older costæ. They are low, rounded or flattish in profile, with shallow, narrow interspaces. Knot-like granulations are discernible along the tops of some costæ.

Calices do not occur in definite series; they are more or less uniformly distributed on the surface, but still there is faint arrangement in series parallel to the growing edge. Diameter of the calices from 2.75 to 3.75 mm.; distance between calicinal centers from 2 to nearly 5 mm., average about 3 mm. The intercorallite areas are flattish, crossed by strongly alternating septo-costæ, about 9 within 2.5 mm. The tall costæ are as much as 1 mm. in height, 0.25 mm. thick at the base; sharp-edged, and dentate on the margins, 4 dentations within 4 mm. The small costæ are low and thin.

There are about 6 large septa to a calice, with 1 to 3 small septa between each pair of large septa, about 38 septa in a large calice. Septal margins faintly dentate; those of the large septa fall perpendicularly to the bottom of the rather narrow columellar fossa. Faces with rather coarse granulations.

Columella, a compressed, erect, axial style.

Synapticulæ well developed, conspicuous between the septo costæ.

Locality and geologic occurrence.—Trinidad, station 8299, Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353664.

The holotype may be only the edge of a corallum of massive growth form. However, that may be, the most closely related known species is the living *Pavona gigantea* Verrill from the Pearl Islands, Bay of Panama.[1]

[1] Verrill, A. E., Conn. Acad. Arts and Sci. Trans., vol. 1, p. 543, pl. 9, fig. 7, 1870. Vaughan, T. W., Carnegie Inst. Wash. Pub. 213, p. 135, 1918.

Pavona trinitatis Vaughan, new species.

Plate 5, Figures 1, 1*a*, 2, and 2*a*.

Description of holotype.—Corallum forming irregularly shaped plates that may be as much as 20 mm. thick.

Outer surface without epitheca, very finely costate; within 2 mm. are 12 low, subequal costæ, with small granulations on their summits.

Calices without definite arrangement, rather uniformly distributed over the surface; they are polygonal, usually oblong. Diameter ranges from 1.75 mm. in regularly polygonal calices to 1.75 mm. wide by 3 mm. long in oblong calices; depth about 1 mm. Distance between calicinal centers from 1.5 to 3 mm. Intercorallite areas range in width from mere dividing-walls, about 0.3 mm. or even less across, up to 1.2 mm. across. Where wide, the intercorallite areas are flat and are crossed by low, equal, relatively thick, crowded, obtuse, septo-costæ, *from 8 to 11 within 2 mm. or between 4 and 6 to 1 mm.*

Septa in calices not dividing range from 15 to 21, about 8 of which as a rule extend to the columella; the other septa are smaller and shorter. The septa not specially thickened in the wall. Septal margins subentire, very faintly dentate. Septal faces without conspicuous granulations.

Columella a stout, erect, compressed, axial papilla.

Synapticulæ greatly developed, very conspicuous between the septo-costæ. Dissepiments present, nearly horizontal or slope downward toward the axis of the corallite; distance apart about 0.5 mm.; it may be somewhat more or somewhat less.

Description of paratype.—Specimen a fragment of a unifacial plate with a thin growing-edge; 3 mm. thick at a distance of 21 mm. from the growing-edge.

Outer surface similar to that of the holotype.

One of the calices is 2.5 mm. wide by 3 mm. long, larger than any calice in the holotype. The distance between the centers of adjacent calices is usually as much as 2.5 mm., and in places is as much as 3.5 mm. The intercorallite areas are wide and flat, and 11 equal septo-costæ were counted within 2 mm. Except that some of them are sharp-edged, the septo-costæ are as in the holotype.

The large calice, the measurements of which are given above, has about 45 septa, more than twice as many septa as the holotype. Of these 45 septa, 8 are more prominent than the others and extend to the columella. Between each pair of large septa are smaller septa without definite cyclical arrangement—in two systems there appear to be members of a second, third, and fourth cycle, decreasing in size according to cycle, but this arrangement is not usual. The larger number of septa in the calices of the paratype is incident to the wider intercorallite areas and the opportunity for more septo-costæ to develop. The small septa have septo-costæ as well as the large septa, but the small septa do not extend far into the calicular cavity.

Other characters as in the holotype.

Locality and geologic occurrence.—Trinidad, station 8299, Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353665.

Paratype.—U. S. Nat. Mus. Cat. No. 353666.

Pavona trinitatis is closely related to *P. panamensis* Vaughan from the Emperador limestone of the Panama Canal Zone. *P. panamensis* has 6 or 7 septo-costæ to 2 mm. Where the calices are distant and the septo-

costæ are equal, while *P. trinitatis* has 11 septo-costæ within the same distance, *P. panamensis* also differs in its more massive growth form. Certain distinct characteristics of *P. trinitatis* are printed in italics in the foregoing description.

Pavona machapooriensis Vaughan, new species.

Plate 5, Figures 4 and 4*a*.

Description of holotype.—Corallum a reflexed plate with calices only on the external surface. Width of plate 28 mm.; maximum thickness where flexed 8.5 mm.; thickness of one leaf of plate near place of flexure 3.5 mm.; about 1.5 mm. thick just within the growing edge. Height not determinable as the specimen is broken, but it exceeds 36 mm.

Common wall without calices, but its ornamentation is concealed by closely adherent matrix.

Calices not arranged in series, rather uniformly distributed, more or less polygonal in outline. Diameter from 1.5 to 1.75 mm.; where division is almost complete the length may be as much as 2.75 mm. Depth, about 0.75 mm. Distance between calicinal centers from 1.3 to 3 mm. Intercorallite areas range in width from mere dividing walls up to 1 mm. Where wide the intercorallite areas are crossed by low, equal, thick, crowded, obtuse septo-costæ, *of which there are 6 or 7 within 2 mm.*

Septa distinctly thicker in the wall than within the calice; about 8 reach the columella the total number between 16 and 18.

Columella a stout, erect, axial style.

Synapticulæ stout, conspicuous between the septo-costæ. Dissepiments were not observed.

Locality and geologic occurrence.—Trinidad, station 8301, Machapoorie Quarry; lat. 10° 27′ 25″ N., long. 61° 14′ 35″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353667.

Pavona machapooriensis differs from *P. trinitatis* by its coarser septo-costæ (6 or 7 within 2 mm.) and the thickened outer ends of its septa. Its septo-costæ are similar to those of *P. panamensis*, but its calices are smaller and its growth form, a relatively thin reflexed plate, is different. Certain distinctive characteristics of *P. machapooriensis* are printed in italics in the description.

Leptoseris walli Vaughan, new species.

Plate 6, Figures 1, 1*a*, and 1*b*.

Description of holotype.—Corallum a thin, unifacial, more or less undulating plate. Some specimens of the complete corallum may be infundibuliform. Width 56 mm.; height 50 mm.+, specimen broken on proximal side; thickness about 2.25 mm. at the proximal edge; growing-edge thin and sharp.

Common wall without calices, no epitheca, very finely costate.

Calices in more or less indefinite series parallel to the growing edge of the corallum; shallow, but with distinct, excavated central cavities. Diameter about 2 mm.; distance between centers in the same series from 1.75 to 4 mm.; distance between centers of successive series along a radial line from 3.5 to 8 mm. Calicular margins either level with the intercalicular areas or very slightly swollen on the proximal side.

Intercalicular areas flat where the calices are distant, gently arched where the calices are near together; crossed by fine, low, thin septo-costæ that alternate in size, 10 septo-costæ (5 larger and 5 smaller) within 2 mm., 24 septa-costæ within 5 mm. Edges of the septo-costæ sharp and finely dentate, about 17 minute teeth within 2 mm.

The number of septa around the edges of a fully developed, more or less isolated calice, about 2.75 mm. in diameter, ranges from about 28 to 36; about every second or third septum, 10 or 12 in all, extend to the columella. The principal septa are slightly taller as well as longer than the other septa, but the difference in size is not very pronounced.

The columella is either a weak or a stout axial papilla.

Synapticulæ small, crowded, distinct between the septo-costæ.

Locality and geologic occurrence.—Trinidad, station 8299, Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353670.

There is in the American Tertiary formation only one known species of *Leptoseris* that is nearly related to *L. walli*. It is *L. antiguensis* Vaughan from an upper bed in the Antigua formation of Rifle Butts, Antigua. *L. walli* has more numerous septa and smaller and more crowded septo-costæ than *L. antiguensis* and its columella is an axial papilla.

One small specimen which Doctor Hoffmeister refers to this species was received from Mr. Bullbrook subsequent to the description of the holotype. It agrees with the holotype in all respects except that the calices are more numerous, are much closer together (1 to 5 mm. apart and averaging 3 mm.), and that there is very little evidence of their arrangement in series. They are simply closely and irregularly grouped together. The columella can be seen to better advantage than in the holotype and is a stout papilla compressed in the direction parallel to the greater diameter of the calice.

Siderastrea siderea (Ellis and Solander).

1786. *Madrepora siderea* Ellis and Solander, Nat. Hist. Zooph., p. 168, pl. 49, fig. 2.
1919. *Siderastrea siderea* Vaughan, U. S. Nat. Mus. Bull. 103, pp. 438, 443, pl. 114, figs. 2 and 3; pl. 122, figs. 1, 2, 2*a*, 3 and 3*a* (with synonymy and references).

An essentially typical specimen was obtained at the following locality:

Locality and geologic occurrence.—Trinidad, station 8298, Nariva Road Quarry, lat. 10° 23′ 40″ N., long. 61° 17′ 10″ W.; collected by F. W. Penny; U. S. Nat. Mus. Cat. No. 353671.

Siderastrea siderea ranges in geologic age from middle Miocene (horizon of the Bowden marl) to Recent.

Psammocora trinitatis Vaughan, new species.

Plate 6, Figures 2 and 2*a*.

Description of holotype.—Corallum pulvinate, massive. The holotype is a fragment with horizontal dimensions of 70 by 75 mm., thickness about 41 mm.

Calices vary greatly in size, range in diameter from about 2 to nearly 6 mm.; large, well-developed, solitary calices are about 4 mm. in diameter. There are many short calicinal series that contain from 2 to 4 calicinal centers and correspondingly range in length from 4.5 to 9 mm.; calicular cavities excavated, with sloping sides, about 2 mm. deep, with an abruptly depressed axial pit. Corallite walls imperfect, synapticulate, greatly perforate.

The septa are thick, coarse, very rough, and greatly perforate. The number varies with the size of the calices. A calice 4 mm. in diameter has 30 septa, of which 12 extend to the columella, the other septa are irregularly grouped around and fused to older septa. As a rule the thickness of the septa is greater than the width of the interseptal loculi. The septal margins are not only roughly dentate, but they also bear the peculiar erect processes from which the genus originally received its name. There are in the better preserved large calices two or three crowns of these processes, the most constant of which rises inside the calicular cavity and as a rule is composed of a process

on each of six large septa. These processes are as much as 0.5 mm. wide, 1 mm. tall, 0.25 mm. thick, and are coarsely granulate. There may be a crown of such processes near the peripheries of the calices, and other, but smaller, processes may stand around the columella pit. The septal faces are coarsely granulate; synapticulæ highly developed.

The columella is formed by the fusion of the inner ends of the large septa; it is not conspicuously developed.

Locality and geologic occurrence.—Trinidad, station 8299, Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353672.

Psammocora trinitatis is the first fossil species of the genus to be recorded from America. *Psammocora* is an important coral on the reefs of the Indo-Pacific.

Psammocora wyckoffi Hoffmeister, new species.

Plate 7, Figures 1 and 1*a*.

Description of holotype.—Corallum consists of an incrusting fragment. The entire corallum may have been of massive growth form, with the edges spread out over and incrusting a piece of foraminiferal limestone. The dimensions of the fragment are 43 mm. by 34 mm. in a horizontal plane, and from 3 to 5 mm. thick. A small part of the under side is exposed and reveals an epitheca clothing well-developed, subequal costæ, of which there are about 9 for every 2 mm.

The upper surface is covered with calices which are either solitary, the usual condition, or two or three calices may occupy a single valley. The average-sized solitary calices measure 3.5 mm. in diameter and 1.5 mm. in depth. The calicinal series, which contain two calicinal centers, average 5.5 mm. in length. Corallite walls irregular, synapticulate, made up of loosely joined processes.

The septa are distinct, but the septal margins appear to be worn; some margins, however, possess small granulations. There are about 18 septa to the average-sized solitary calice, 12 of which appear to reach the columella tangle, the other 6 being irregularly grouped around and fused to the older septa. The spaces between the septa usually exceed in width the thickness of even the thickest septa. The septa are somewhat thickened in the wall. The septal faces are covered with sharp granulations. The septal margins do not bear the erect processes so common in many species of *Psammocora*. The surface of the corallum is somewhat worn and it is possible that these may have been rubbed off. I doubt, however, if they were ever very prominent.

The mural reticulum is loosely constructed and appears as a network between the calices.

The columella is a tangle formed by the irregular fusion of the ends of the larger septa. It appears to be granulate.

Locality and geologic occurrence.—Trinidad, station 9286. Quarry 0.25 mile down the Hindustan Junction branch road, which runs south from mile 13½ on the San Fernando-Mayaro main road; from Amphistegina limestone; collected by F. W. Penny.

Holotype.—U. S. Nat. Mus. Cat. No. 353677.

Psammocora wyckoffi is distinct from *P. trinitatis* Vaughan by the apparent lack of erect processes on the septal margins, the fewer septa, and the wider septal interspaces. The calices of *P. gasparillensis* Vaughan are smaller.

Psammocora gasparillensis Vaughan, new species.

Plate 7, Figures 2 and 2*a*.

Description of holotype.—Corallum pulvinate in form, exceeds 75 mm. in horizontal diameter, thickness in the center about 22 mm., about 4 mm. thick just within the growing-edge.

Calices excavated, with a central pit; irregular in shape and variable in size. The form of the calices is subcircular or elliptical where they are entirely or nearly isolated. The range in diameter of such calices is from 2.5 to 3.75 mm. Poorly defined series, with as many as 4 calicinal centers, may attain a length of as much as 6.5 mm. Distance between calicinal centers ranges from 1.5 to 2 mm. in the same series, range between opposite centers in adjacent series from 2 to 3 mm. The intercalicular reticulum is composed of costæ and synapticulæ and is gently curved on its summit. The depth of the calices is about 0.75 mm.

The number of septa in the large single calices is about 18, half of which reach the columella tangle some of the larger septa appear to fork before they reach the wall. There are in the smaller calices from 12 to 15 septa, of which about 8 or 9 extend to the columella; some large septa in these calices appear to fork near the center of the calice, while in a few interseptal loculi rudimentary septa are introduced at the wall. The septal arrangement is irregular, and the septa are coarse and rough. Within the wall the septa in general are solid and thick, with narrow interspaces which are crossed by synapticulæ near the columella and near the wall. The wall is synapticulate. There is an irregular crown of paliform knots around the columella; other knots may stand on the margins of the larger septa rather near the wall; and there may be other knots along the boundaries between adjacent corallites. Although the septal knots are fairly large and give the surface a rough appearance, they are not so thick, so wide, or so tall as in *Psammocora trinitatis*.

The columella pit is abruptly sunken and has a diameter of about 0.75 mm. at its mouth. In many calices there is a central columellar tubercle, but I am not sure that it is constantly present.

Synapticulæ thick and coarse, present near the columella and near the wall, and they form the wall, which is perforate and interrupted.

Locality and geologic occurrence.—Trinidad, station 8297, Gasparillo Quarry; lat. 10° 19′ 50″ N., long. 61° 25′ 10″ W. (holotype and one other specimen); station 8298, Nariva Road Quarry; lat. 10° 23′ 40″ N., long 61° 17′ 10″ W. Collections made by F. W. Penny. Dominican Republic, station 8668; Baitoa formation. Haiti, stations 9945 and 9947, Thomonde formation.

Holotype.—U. S. Nat. Mus. Cat. No. 353673.

Psammocora trinitatis has much larger calices and it has taller and coarser septal processes than *P. gasparillensis*.

Porites trinitatis Vaughan, new species.

Plate 6, Figure 3; Plate 7, Figures 3 and 3*a*.

Description of the holotype.—The corallum forms thin plates, on the surface of which are a few low gibbosities. The holotype, which is broken around all its edges, has a maximum width of 95 mm. and attains a maximum thickness of 9 mm. Calices are present on both faces of the corallum, but I am not certain whether the plates are truly bifacial or whether the growing-edge has pushed over one side of the plate from the main calificerous surface.

Calices polygonal, rather shallow. Diameter from 1.25 to 1.8 mm., about 1.6 mm. usual.

Walls ragged, zigzag, much interrupted, narrow, no intercorallite reticulum. Mural denticles irregularly developed, of about the same number as the septa, more or less twisted, as a rule compressed in a tangential plane.

The normal number of septa is 12; they are rather thick at the wall but become thinner toward the columellar tangle. The normal arrangement appears to be a solitary directive, a directive triplet, and 4 lateral pairs, but because of imperfect preservation the arrangement can be distinguished in only a few calices. There seems to be some asexual reproduction by fission and consequent irregularity in the septal scheme. The inner ends of the lateral members of the triplet, at least in some calices, are directed toward the inner ends of the directive member of the group and are fused to it at the palus. Between the palar crown and the wall there is, as a rule, on each septum a prominent denticle that is detached from the wall; on about half the septa there is between the outer circle of denticles and the palar crown a smaller denticle. The septal faces are rough. The outer synapticular ring imperfectly developed.

The pali are small, thin, erect, and rodlike; usually 5 in number. The palar synapticular ring more or less incomplete.

Columella, a small tubercle.

Localty and geologic occurrence.—Trinidad, stations 8299 and 9217, Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; collected by F. W. Penny and J. A. Bullbrook.

Holotype.—U. S. Nat. Mus. Cat. No. 353674.

Porites anguillensis Vaughan forms more or less flexed plates that are epithecate on the base. Its calices are separated by intercorallite reticulum, its component trabeculæ are much coarser than in *P. trinitatis*, and its septal arrangement is different.

Porites sp. aff. P. porites (Pallas).

1766. *Madrepora porites* Pallas, Elench. Zooph., p. 324.
1919. *Porites porites* Vaughan, U. S. Nat. Mus. Bull. 103, p. 498.

A single piece of a colony of a species of *Porites* from Trinidad has the growth form, the general calicular characters, the septal arrangement, and the palar formula of *Porites porites*. There are, as a rule, on each septum two distinct septal granules between the palus and the wall. The outer granule is detached from the wall and is prominent; the granules of this crown are joined together by a ring of synapticulæ and a very well-developed mural shelf is formed.

Locality and geologic occurrence.—Trinidad, station 6299, Cumuto Road, mile 17, lat. 10° 28′ 30″ N., long. 61° 13′ 25″ W.; collected by F. W. Penny.

The stratigraphic range of *Porites porites* is from the Miocene La Cruz marl of Cuba to Recent. The geologic horizon indicated by the presence of that species is not below lower or middle Miocene.

Porites sp. aff. P. astreoides Lamarck.

1816. *Porites astreoides* Lamarck, Hist. nat. Anim. sans Vert., vol. 2, p. 317.
1918. *Porites astreoides* Vaughan, U. S. Nat. Mus. Bull. 103, p. 503.

Several specimens from Trinidad have the growth form, the general corallite characters, and the septal arrangement of *Porites astreoides*, but, as the details of the calices and of the septal margins are not exhibited, positive specific identification is impracticable.

Localities and geologic occurrence.—Trinidad, as follows: Station 8297, Gasparillo Quarry; lat. 10° 19′ 50″ N., long. 61° 25′ 10″ W.; station 8299,

Cumuto Road, mile 17; lat. 10° 28′ 30″ N., long. 61° 13′ 35″ W.; station 9286; Quarry 0.25 mile down the Hindustan Junction branch road, which runs south from mile 13.5 on the San Fernando-Mayaro main road. Amphistegina limestone. Collections made by F. W. Penny.

Porites astreoides was formerly known to range from the Miocene La Cruz marl of Cuba to Recent. The presence of a species of *Porites* of the aspect of *P. astreoides* at the above-mentioned localities indicates a geologic age not greater than Miocene.

EXPLANATION OF PLATES.

PLATE 1.

FIGS. 1, 1*a*. *Sphenotrochus trinitatis* Vaughan, n. sp.
1. Side view of corallum, ×5. 1*a*. Calice, ×5.

FIGS. 2, 2*a*. *Sphenotrochus brassensis* Vaughan, n. sp.
2. Side view of corallum, ×5. 2*a*. Calice, ×5.

FIGS. 3, 3*a*, 3*b*, 4. *Placocyathus trinitatis* Vaughan, n. sp.
3. Side view of corallum, cotype No. 1, natural size. 3*a*. View of narrower side, cotype No. 1, natural size. 3*b*. Costæ, cotype No. 1, ×4. 4. Cut transverse section of cotype No. 2, ×2.

FIGS. 5, 5*a*, 6, 7. *Stylophora imperatoris* Vaughan.
5. Specimen No. 1, corallum, natural size. 5*a*. Specimen No. 1, calices, ×6.
6, 7. Specimens from same locality as specimen No. 1, natural size.

PLATE 2.

FIG. 1. *Stylophora imperatoris* Vaughan. Corallum of specimen from Machapoorie Quarry, natural size.

FIGS. 2, 2*a*, 2*b*, 3. *Asterosmilia trinitatis* Vaughan, n. sp.
2. Side, natural size. 2*a*. Calice. ×2. 2*b*. Costæ, ×4. 3. Cut transverse section, ×2, of another specimen.

FIGS. 4, 4*a*, 4*b*, 4*c*, 5. *Asterosmilia machapooriensis* Hoffmeister, n. sp.
4, 4*a*. Cotype No. 1, views of corallum, natural size. 4*b*. Costæ at calicular rim, ×4. 4*c*. Calice, ×2. 5. Cotype No. 2, cut transverse section, ×2.

FIGS. 6, 6*a*. *Antillia sawkinsi* Vaughan, n. sp.
6. Side view, natural size. 6*a*. Calice, natural size.

FIGS. 7, 7*a*, 8, 8*a*. *Antilla bullbrooki* Hoffmeister, n. sp.
7. Side, natural size, of holotype. 7a. Calice, natural size. 8. Side, natural size, of No. 4. 8*a*. Calice, natural size.

FIG. 9. *Placocyathus trinitatis* Vaughan, n. sp., corallum, natural size.

PLATE 3.

FIGS. 1, 1*a*, 1*b*. *Orbicella limbata* var. *pennyi* Vaughan, n. var.
1. Corallum, natural size. 1*a*. Polished transverse section ×3. 1*b*. Cross-section of corallites in thin section, ×4.

FIGS. 2, 2*a*. *Orbicella altissima* (Duncan).
2. Top of corallum, natural size. 2*a*. Cross-section of corallites in thin section, ×4.

FIGS. 3, 3*a*. *Orbicella cumutensis* Hoffmeister, n. sp.
3. Calices, natural size. 3*a*. Calices, ×3.

PLATE 4.

FIGS. 1, 1*a*. *Orbicella trinitatis* Vaughan, n. sp.
1. Calices, natural size. 1*a*. Calices, ×3.

FIGS. 2, 2*a*. *Goniastrea trinitatis* Vaughan, n. sp.
2. View of cut transverse section of corallum, natural size. 2*a*. Same, ×4.

FIG. 3. *Mycctophyllia bullbrooki* Vaughan, n. sp. Top view of corallum, natural size.

PLATE 5.

FIGS. 1, 1*a*, 2, 2*a*. *Pavona trinitatis* Vaughan, n. sp.
1. Holotype, corallum, natural size. 1*a*. Calices, ×4. 2. Paratype, corallum, natural size. 2*a*. Calices, ×4.

FIGS. 3, 3*a*, 3*b*. *Pavona pennyi* Vaughan, n. sp.
3. Corallum, natural size. 3*a*. Under surface of corallum, natural size. 3*b*. Calices, ×3.

FIGS. 4, 4*a*. *Pavona machapooriensis* Vaughan, n. sp.
4. Corallum, natural size. 4*a*. Calices, ×4.

PLATE 6.

FIGS. 1, 1*a*, 1*b*. *Leptoseris walli* Vaughan, n. sp.
1. Corallum, natural size. 1*a*. Calices, ×2. 1*b*. Calices, ×4.
FIGS. 2, 2*a*. *Psammocora trinitatis* Vaughan, n. sp.
2. Corallum, natural size. 2*a*. Calices, ×4.
FIG. 3. *Porites trinitatis* Vaughan, n. sp. Calices, ×6.

PLATE 7.

FIGS. 1, 1*a*. *Psammocora wyckoffi* Hoffmeister, n. sp.
1. Corallum, natural size. 1*a*. Calices, ×4.
FIGS. 2, 2*a*. *Psammocora gasparillensis* Vaughan; n. sp.
2. Corallum, natural size. 2*a*. Calices, ×4.
FIGS. 3, 3*a*. *Porites trinitatis* Vaughan, n. sp.
3. Corallum, natural size. 3*a*. Calices, ×6.

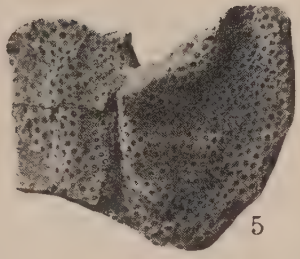
1

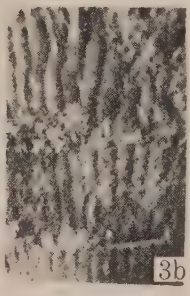
2

2a

3

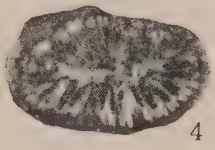
3a


5


3b

5a

1a

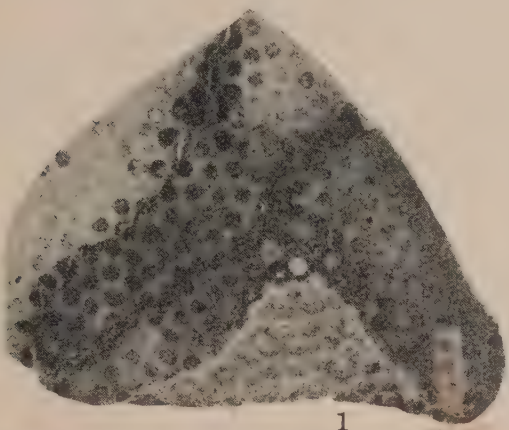

4

6

7

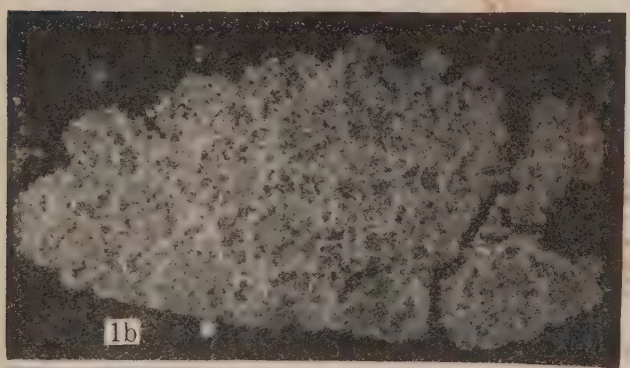
For description, see Explanation of Plates, page 133.

For description, see Explanation of Plates, plate 133.



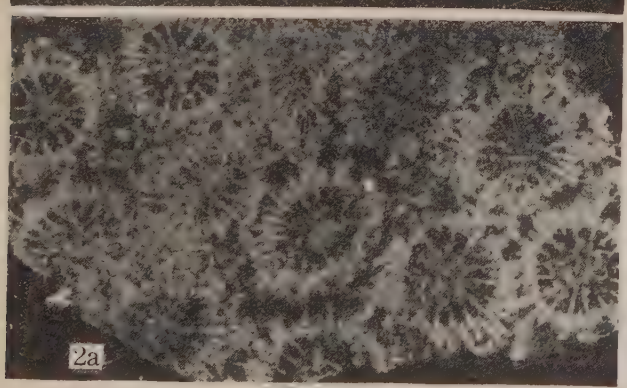
1

1a



1b

2

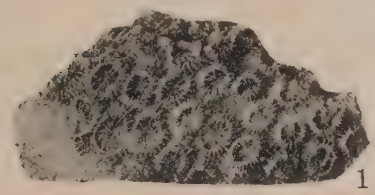


2a

3a

3

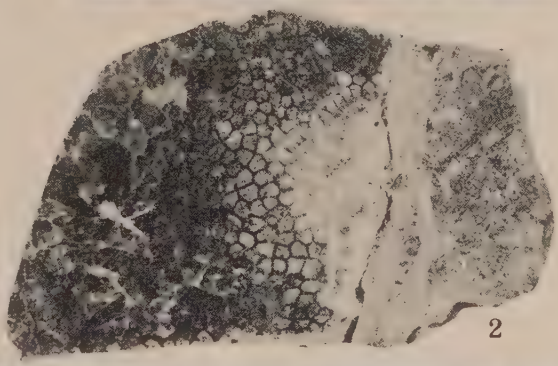
For description, see Explanation of Plates, page 133.



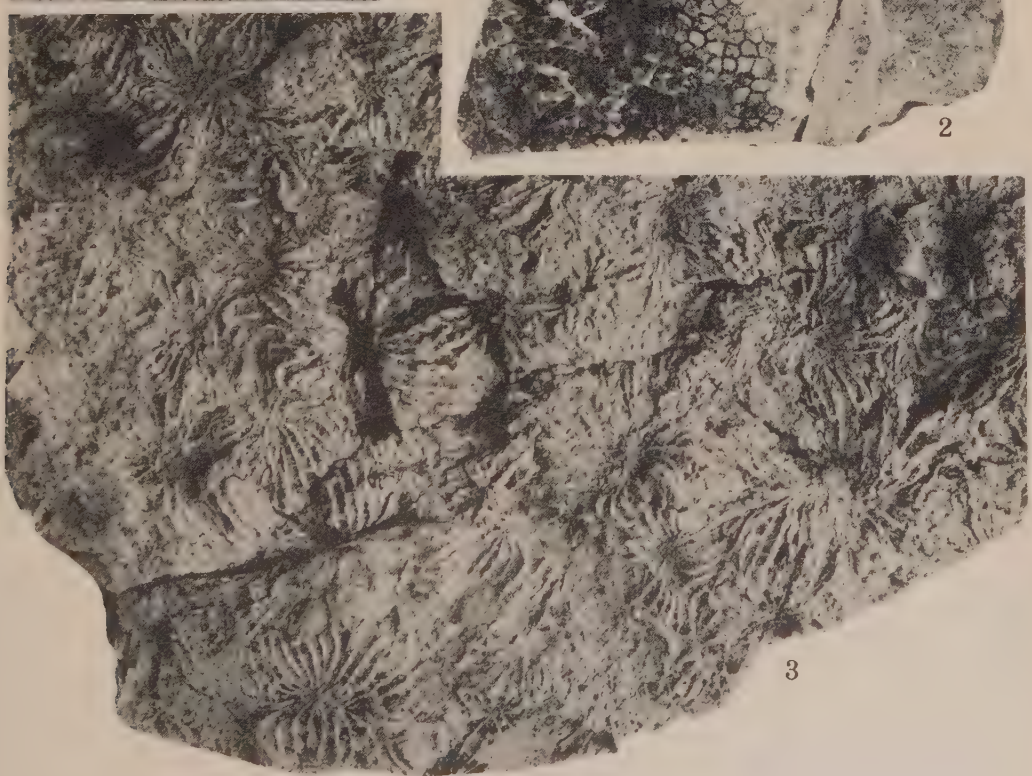
1

1a

2a



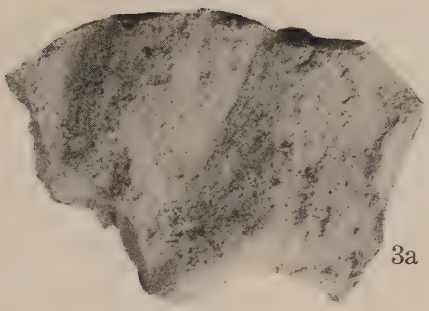
2



3

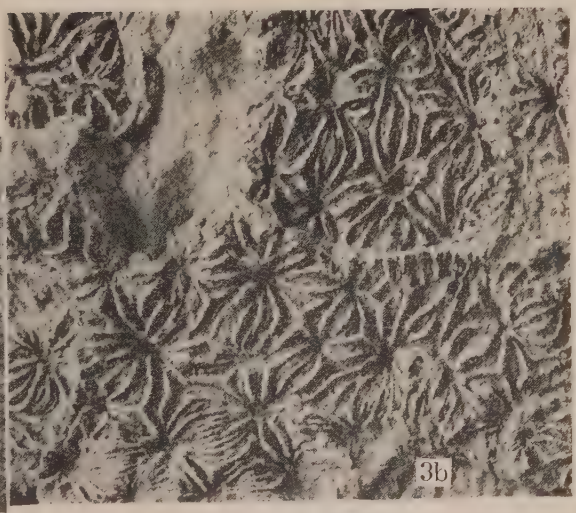
For description, see Explanation of Plates, page 133.

1

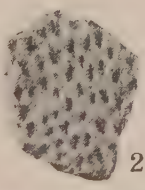

3a

3

1a


3b

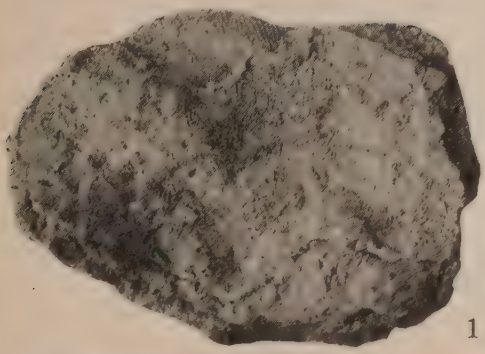
2a


2

4

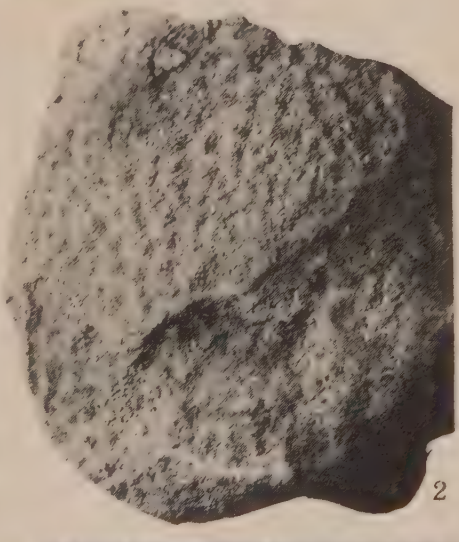
4a

For description, see Explanation of Plates, page 133.


1

1a

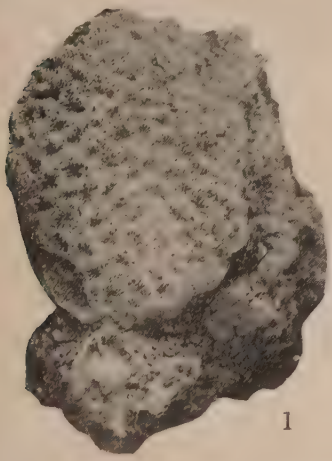
1b

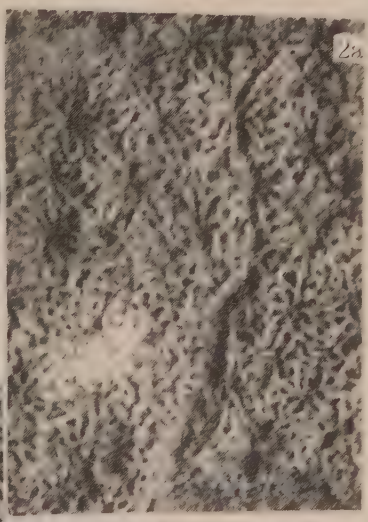

2

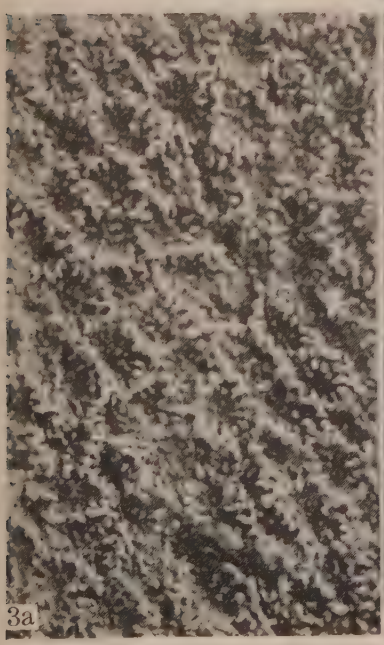
2a

3

For description, see Explanation of Plates, page 134.







For description, see Explanation of Plates, page 134.